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By E. FARMER, M.A.

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PREFATORY NOTE.

The Board in their Preface to Report No. 12 have already given the reasons which induced them to pay some attention to vocational guidance and selection. Time and motion study, which is dealt with in the present Report, is a fitting complement to vocational selection, in that it aims at providing standard methods of training to beginners who may have already been selected for the work on the basis of their natural aptitudes. Vocational Selection, therefore, is an antecedent to employment; time and motion study a method to be applied after employment has been accepted.

In this country both subjects are at present in their infancy, though at an early stage of the Board's existence, they were brought into touch with a factory (an iron foundry) in which a complete system of motion study had been in force for some years, with striking results as regards both earnings and output.* Increasing interest, however, has lately been indicated by the formation of the National Institute of Industrial Psychology, a self-supporting organisation formed to study and to give practical effect to these principles.

As a preliminary step, the Board resolved to arrange for the preparation of summaries comprising the past work carried out in these subjects. That on vocational selection was entrusted to Mr. B. Muscio,† and is published as Report No. 12. The present Report by Mr. E. Farmer embodies an account of the whole of the past work (so far as it can be traced) carried out in time and motion study. It also contains a description of some preliminary experiments carried out by him in a confectionery factory, and the Board wish to express their cordial thanks to Messrs. Pascall's of London, for facilities for the investigation so generously given.

The results of a further investigation based on time and motion study in metal polishing have now been published.‡

Oct. 1921.

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*Myers, C. S. (1919): Improved Methods in an Iron Foundry, *Industrial Fatigue Research Board, Report No.* **3.**

†Muscio, B. (1921): Vocational Guidance. (A Review of the Literature) *Industrial Fatigue Research Board, Report No.* **12.**

‡Farmer, E. (1921): Motion Study in Metal Polishing, *Industrial Fatigue Research Board, Report No.* **3.**

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TIME AND MOTION STUDY.

By Eric Farmer, M.A., *Investigator to the Board.*

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PART I.—REVIEW OF PAST WORK.

§1. Introduction.

Time and motion study has become a phase of common occurrence in industrial circles, but there is little agreement as to its precise significance and little understanding how, and to what extent, such a study can be of use to industry. There are some who consider that a little attention to the time taken to perform an operation, and the method of doing it, should be sufficient to "at least treble output." There are others who form a much lower estimate of the probable value of these methods and who consider it presumptuous for an outsider to come into a factory to teach others how to do their work. The truth as to the function of the study probably lies somewhere between these two extremes, but it is more likely to approximate towards the latter than the former. To talk of trebling output may be useful for commercial purposes, as being likely to attract the attention of those anxious to improve industrial methods, but if it is to be taken in its literal sense it is most misleading. Any one who has carefully studied the subject in any industry, must be impressed not so much with the ease of effecting improvements as with the practical difficulty involved in so doing.

We may define time and motion study in the following manner:—

Time Study is the study of the time taken to perform each particular operation in an industrial task, and from the data thus obtained, endeavouring to fix the proper time the task as a whole should take.

Motion Study is the study of the movements involved in a task with a view to eliminating such as are unnecessary and improving those that are necessary. It may be divided into *Extensive Motion Study*, which is concerned with the arrangement of apparatus and the larger movements of the body involved in its use, and *Intensive Motion Study*,* which is concerned with the smaller movements of the hands and fingers.

Time study and motion study are usually combined into one study, called time and motion study.

In order to understand what we may expect from time and motion study we must first consider its origin and present development, and endeavour to understand what are the exact aims that those engaged in it set before themselves, how far these aims are legitimate, and how far they can be attained by the present methods.

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*The term "*Micro Motion Study*" is not adopted here since it has been defined by Gilbreth as the study of the minute movements of the hand and fingers by means of the Cyclechronograph. For reasons that will be advanced later in this report it does not appear that these small measurements need always be studied by the method adopted by Gilbreth.

§2. TAYLOR'S SYSTEM.

The object Taylor set before him was the standardisation of labour, and, in order to arrive at the proper standard, he instituted a system of time study. His method was to divide work into its various elements and time them separately. The results were then summed and a certain percentage added for unavoidable delays. Taylor's practice was to time first-class men who were induced to work as fast as possible by increased remuneration. As soon as the time study had been made, a workman was started on his new "task," which "required him to do between three and one half and four times as much work in a day as had been done in the past on an average."*

The earnings of the men on the new system were on an average 60 per cent. greater than on the old system. The result was attained not so much by any improvement in the movements involved in doing the work, as by fixing a certain standard time which had to be adhered to if the men were to earn the sum which they were obliged to earn in order to keep their places. Scientifically regulated rest pauses were also introduced, and these undoubtedly played an important part in the final result. Taylor advocated making the "task" as difficult as possible, so that only the best men could perform it. By this method he gradually eliminated all so-called second-class men.

Taylor's formula for the time required for doing any specific piece of work is the sum of *the units of the work* multiplied by 1 + P, where P equals "*percentage of a day required for rest and necessary delays.*"† A unit of work is the smallest possible sub-division of an operation that can be usefully timed.

He does not, however, tell us exactly what he means by "rest and necessary delays," but only that he handed his data to C. G. Barth, who worked them out graphically.‡ This is unfortunate, as it is really the most important part of his work. Without this knowledge we are left with the impression that Taylor's success was mainly due to a general speeding up of the work by means of increased remuneration for those who came up to the required standard, and dismissal in the case of those who did not. Taylor was careful to choose not only men who were industrious and desirous of earning higher wages, but also such as had the necessary physical strength to sustain the increased effort demanded of them. This does not mean that he instituted a system of scientific vocational selection, but that he used his experience and common sense in choosing his men, and if, after a trial, they were unable to obtain the standard he required, he

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* *Shop Management*, by F. W. Taylor, New York, 1911, Harper, p. 49.

† *Shop Management*, p. 159. Examination of the arithmetical examples given by Taylor indicates that the definition of P (as given on pp. 159 and 163) is wrong in two respects, and that instead of "*the percentage of a day required for rest, etc.,*" it should be "*the ratio of the time required for rest, etc., to the time spent in work.*"

‡ *Princ. Sci. Management*, pp. 56, 57.

substituted others for them. In the experiments he carried on with men loading pig iron, about one in eight of the men were capable of reaching the standard Taylor had set.

Such a system may be commercially advantageous but it hardly goes to the root of the fundamental problems connected with the human element in industry. Much of Taylor's work is devoted to what he calls Scientific Management and a consideration of the best method of remuneration.* The scope of the present memorandum does not extend to these aspects of Taylor's system ; nevertheless, they form an essential part of his system, which rests more upon careful oversight and liberal payment than upon scientific principles connected with the human organism.

An interesting example of Taylor's work is the experiment he carried out on some girls examining bicycle balls in the Symonds Rolling Machine Company. One hundred and twenty girls were employed in examining bicycle balls for various kinds of defects. They allowed the balls to run over their left hand and extracted the imperfect ones with the right. Their working hours were 10½ per day and they were on day work. The day work was changed to piecework and the hours were reduced from 10½ to 9½ and finally to 8½ hours per day. Under the new conditions 35 girls were able to do the same amount of work previously done by 120, in spite of the fact that they worked 8½ hours per day instead of 10½. They earned from 6.50 to 9.00 dollars per week on piecework while when they worked on day work their earnings had averaged from 3.50 to 4.50 dollars per week. This means that each girl of those left by the final selection did 3·4 times as much work as she had done before, while she received an increase of 93 per cent. on her previous earnings.

Taylor says that when the girls worked 10½ hours per day a considerable amount of their time was spent in talking and idling. This statement is in agreement with the well-known fact that if working hours are too long, the worker unconsciously adapts himself to them, and by working a considerably shorter time than he is supposed to do, protects himself against much of the harm that would otherwise be caused by long hours. One would expect that by reducing the hours of such an exacting task as examining bicycle balls for minute defects, the quantity and quality of the work would be improved.

Taylor gives two accounts of this experiment. In the former no mention is made of scientific selection : in the latter it is not only mentioned, but said to be " the one element which did more than all of the others " to bring about the improvements effected. It is not definitely stated whether the girls finally selected for the work were among the original hundred and twenty, but by speaking of " old hands " he certainly gives that impression.†

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* *Incentives to Work.* Interim Report Health of Munition Workers' Committee.

† *cf.* Muscio (1921) : Vocational Selection, *Industrial Fatigue Research Board Report No.* 12 (*Appendix*).

Munsterberg * claims this experiment of Taylor's as an instance of the proper use of scientific selection, but a close examination inclines one to think that the shortening of hours, the introduction of rest pauses and standardisation, played an equally large part in the general results.

Taylor regards this experiment as an excellent illustration of what can be done to increase output by "measuring a man's performance against a given task at frequent intervals." The "task" was set by the method of timing above described, and then the performance of each girl was compared with that of the task she was supposed to fulfil. If they were falling below what was expected of them, an assistant was sent round to encourage them to put forth greater effort. This comparison between the standard task and actual performance took place every hour, and the girls were informed of the result. By this method they were kept constantly at their highest pitch. The pay of those who turned out a large quantity was increased and the pay of those who failed to come up to the standard was decreased.

The above example of Taylor's work has been given in some detail because it is typical of his whole method. First, the "task" is set by accurate timing and made as high as possible. Then the work of the girls is measured by it every hour, and if they fall off an assistant goes round to "encourage" them (perhaps one may be forgiven for almost unconsciously saying "to goad them on"). If they fall below what is expected of them their rate of pay is decreased; if they come up to standard it is increased.† They were set far apart during working hours and forbidden to talk; once in the morning, and once in the afternoon they were obliged to leave their benches for ten minutes and encouraged to talk. By the process of elimination, the number of workers was reduced, the average earnings of those who remained was in advance of their earnings on the old system. This is supposed to be a very satisfactory result from Taylor's point of view, and strictly speaking, from his point of view it is, for his main object is higher output. Taylor says "no doubt some people will say that these girls were brutally treated," but he points to their gain in higher earnings and shorter hours and assures us they were not. It would, however, be interesting to know what they thought of the "improved" conditions, and what effect it had upon their health and nervous system, and also to hear the views of the girls who were eliminated.

The results obtained by Taylor were not primarily due to improvement in the movements employed in doing the work. They were due rather to shorter hours, the introduction of rest pauses, and various incentives to increased effort. It is now generally recognised that reduction of hours, where they are longer than is physiologically desirable, is beneficial from every

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**Psychology and Industrial Efficiency*, p. 54.

†Taylor: *Piece Rate System*.

point of view, and much credit is due to Taylor for bringing this to light, but his experiment would have been more instructive if it had been done in two parts. First, shortening the hours and measuring the change in output, and then introducing his various forms of incentives, and again measuring the difference. As it is, we are unable to judge which played the greater part in the enormously increased output, and perhaps Taylor's critics are not altogether to blame for assuming that it was probably the latter element that was the more important.

Taylor's most important contribution to the scientific study of industry is the work he did on rest pauses, especially in connection with loading pig iron and shovelling. A study of this problem hardly comes within the scope of the present report, and can be better dealt with in one dealing primarily with rest pauses. Taylor set himself the task of determining what percentage of the day a man should be under load, the proper length of rest pauses, the times at which they should occur, the proper weight to be lifted at each lift of a shovel, and how many times per minute the shovel should be filled and swung.

All these experiments were carried out with great care and accuracy, and much credit is due to Taylor for this very important contribution to the problem of industrial fatigue. In one sense these experiments may be regarded as falling under the head of motion study, since they concern themselves with regulating the movements of the worker; but for purposes of classification they may be regarded as belonging to the sphere of rest pauses. The dividing line between the various elements which make up the study of industrial fatigue is a fine one, and no one study can be carried on by itself if the best results are to be obtained.

A narrow definition of motion study is adopted in this report, and the other factors which have an important bearing on the subject are dealt with under different heads.

In "The Principles of Scientific Management"* Taylor mentions the subject of motion study, but in "Shop Management" the subject is not referred to. The main body of his experiments is undoubtedly concerned with lessening fatigue by the use of proper implements and proper spells of work. It is a far more intricate and difficult problem than that of motion study proper, and our final appreciation of Taylor's work must depend upon his contribution to this problem, motion study proper being more adequately dealt with by Gilbreth. Taylor devoted a considerable amount of attention to the proper speed and shape of cutting tools in engineering shops. He finally claimed to be able to express his results in mathematical formulae, so that a worker could determine by means of slide rules the exact speed at which his lathe should revolve for any particular work, and also the best tool to use for the purpose. He arrived at these results by time study.

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* p. 117.

Considerable controversy has centred round Taylor's work. Some seem to regard all he did as almost beyond criticism. They point to his undoubted successes as sufficient indication of the essential soundness of his method, and regard all who criticise him as actuated by motives less worthy than those of Taylor. On the other hand there are those who regard all he did either with derision or direct hostility. They fasten their eyes on certain weak points in his system and refuse to consider those aspects which are of more lasting value.

To follow either of these extreme courses is unwise. When we think of Taylor's dealings with labour, either organised or unorganised, we must never cease to remember that he is dealing with labour conditions as they presented themselves in America, and not with the conditions with which we ourselves are familiar. When we think of certain parts of his system which may appear somewhat crude, we must remember that he was a pioneer in an unknown field of research, and we ought not to expect that his system could reach the standard of perfection, which those who come after him, and have the benefit of his experience, may set themselves as the goal to be attained. Taylor's great and lasting contribution to the science of industry is the method he adopted. He approached problems which had been thought either not to exist or to be easily solved by common sense, in the spirit of scientific enquiry. He worked patiently for years to satisfy first himself and then others, that by careful observation and accurate timing, principles could be arrived at which governed the right employment of a worker's time and energy. Those who come after him and work upon the same problem may criticise aspects of his system, and disagree with certain of the ends which it has been made to serve, but nevertheless they owe him a great debt for indicating and developing a method the possibilities of which are very great.

§3. Gilbreth's System.

Gilbreth set himself the same task as Taylor, namely, the standardising of the human element in industry; he, however, goes further than Taylor, for not only does he standardise the time for doing a task but he also standardises the method. Taylor is mainly concerned with time study and rest pauses; Gilbreth is concerned with motion study as well.

Gilbreth's method is first to analyse an operation into its smallest constituent parts. These are then timed. With Taylor this would have been sufficient, for he would have taken the sum of these timings, plus the time allowed for unavoidable delays, and called that the standard time. Gilbreth, however, is not satisfied with this, but compares the different constituents of a given operation with the same constituents in a similar operation performed by other operatives. If the timings for different units of the operation differ in different workers, he selects the shortest timings from each operative, sees how the actual movements differ from those of other operatives who

take longer to perform that unit of the task, and then sets a standard time composed of the sum of the shortest constituent factors in each operation, and a standard method of doing the work composed of the movements of those whose time is shortest. Thus with two workers, whom we may call X and Y, he may find the timings of X for an operation consisting of four timeable units to be A, B, C, D and the corresponding times of Y to be a, b, c, d. From these times he will select the shortest, let us suppose these to be A b, C d. He will then examine the motions connected with each of these selected time units, A and C will be found among X's movements, b and d among Y's. These four motions coming from two different workers will then be combined into one series of movements which will be adopted as the standard method of doing the task, the standard time having already been arrived at by selecting the shortest time units from the two workers. This yields two parallel series which may be represented thus :—

Shortest Time	*Motion.*
A	motion as performed by X.
b	,, ,, ,, ,, Y.
C	,, ,, ,, ,, X.
d	,, ,, ,, ,, Y.

This method of procedure is interesting, and is a distinct advance on Taylor's method, which did not concern itself with the actual movements employed, provided that the task was performed in the standard time, the proper rest pauses were adhered to, and the final result was satisfactory to the overseer. Gilbreth sees that the method of doing work plays equally as important a part in the performance of any work as the time taken to do it. Gilbreth's methods would, however, have been more instructive if he had not introduced the disturbing factor that Taylor always introduced, namely, increased pay and various other methods of "encouraging the workers to put forth greater effort."

Further, it seems highly doubtful whether various movements, taken from different groups of movements, merely on account of their taking a shorter time to perform than similar movements in other groups, can be combined into an independent group which would yield results as satisfactory as either of the original groups. The method of performing a given task is similar to the so-called "style" of a cricketer or golfer, who certainly would not build his style on a composite mixture of other people's styles. It is far more satisfactory to study one style and become perfect in that, than to study many which may yield only the result of being imperfect in all. We cannot, however, pass final judgment on the method because it has never been tried by itself unaccompanied by special inducements to increased effort, but the results which Gilbreth has obtained do not prove that there is "*a*" best method of doing any operation. There are, undoubtedly, good methods and bad methods ; the good may be encouraged and the bad discouraged, but the actual method

finally adopted by the worker must be the one which he finds most convenient, that is the one best suited to his physical and psychological make-up. We shall, however, return to this later.

Gilbreth's first studies in timing movements were done by means of the stop watch. This was found not to yield sufficiently accurate results, and he devised more elaborate apparatus. He tells us that he "found it advantageous to photograph the various positions in which the hands, arms, feet and other parts of the body involved in the operation were placed, and to record the time taken in moving from one position to another by one method, as related to the time taken in moving from the same first to the same second position by another method."

He also used the cinematograph camera with a high speed clock, so that an accurate record of all movements and the time taken for their performance was obtained. In order to obtain still greater accuracy a cross-sectioned background and work bench were used, so that it was possible to measure the exact distance and direction of any movement, at the same time that the microchronometer measured the time taken to the millionth part of an hour. Difficulty was, however, still found in visualising the exact path of a movement, and so the cyclegraph was invented. This method of recording motions consists in "attaching a small electric light to the hand or other moving part of the person or machine under observation. The motion is recorded on an ordinary photographic film or plate." By using a stereoscopic camera it was possible to see the path taken by the objects under observation in three dimensions, and these records were called stereocyclegraphs. The stereocyclegraphic method of recording movements gave no corresponding time record. To overcome this difficulty an interrupter was introduced into the light circuit which caused the light to "flash at an even rate at a given number of times per second." A further improvement was made by causing the flashes to appear more suddenly than they disappeared. By this method the direction of the movement could be easily seen. The records are called stereochronocyclegraphs. It is from these stereochronocyclegraphs that Gilbreth had his wire models of movements constructed which have proved of great service for purposes of instruction. An autostereochronocyclegraph apparatus has been invented for the use of those who do not like the presence of an observer while they are working, and double cinematograph cameras have been used in order to do away with the slight gaps that occur in the ordinary cinematograph record. No weight, however, is laid upon the importance of these two latter inventions by Gilbreth.

Besides motion study proper, Gilbreth has done very useful work in determining the right height of workers' chairs and benches so as to allow the body to work in the most comfortable and efficient manner. He has also carried out experiments in the right arrangements of tools so that the worker may find those he requires with the least possible effort. This line of

experiment opens up a field of very useful investigation, and should play a large part in all pioneer work, since it interferes least with the workman's actual movements, and so forms a very useful preliminary to motion study proper.

Gilbreth's greatest contribution to motion study is his work on bricklaying.* It is the book of a specialist written for specialists. Only those fully conversant with the building trade will be able to appreciate it properly, but for such it is well worthy of study. Every detail connected with the processes involved in the trade is given. It is full of interesting photographs showing various methods of saving labour and fatigue, and from this point alone, leaving out motion study altogether, it should be of great help to those interested in the efficiency of the trade.

Gilbreth devotes a good deal of attention in his books to systems of management, remuneration, welfare work, and fatigue study, but these hardly come within the scope of motion study although they are closely allied to it. Research on these subjects would be most helpful to those engaged in motion study, which touches them all very intimately at many points.

§4. Criticism of Taylor's and Gilbreth's Methods.

The work of Taylor and Gilbreth has been dealt with in some detail because it is mainly due to their efforts that time and motion study has reached its present stage of development. As will be seen from the abstracts of the literature referred to, most of the work of first-class importance is due either to Taylor or Gilbreth. A good deal of the literature on the subject merely deals with the work already done, and is more valuable as propaganda than as bringing to light fresh facts in the development of the science. Most of the original contributions outside Taylor and Gilbreth's work deal with improvements effected in moulding and engineering shops. A good many deal primarily with labour-saving devices, and time study is only brought in as a measure of the value of the devices introduced. No new principles are suggested, the writers contenting themselves with the application of the Taylor-Gilbreth systems to the various forms of industry in which they are interested. A criticism of these two writers, therefore, will serve to bring out the principles which, up to the present, have governed the development of time and motion study.

Both Taylor and Gilbreth set before themselves the definite task of standardizing the human element in industry. They wanted to make industry more efficient by reducing the cost of production. Some people when they attempt to reduce the cost of production think primarily of lowering the wages paid to labour, but Gilbreth and Taylor made no such mistake. They both realised that to reduce the cost of production by such a method is, in ordinary circumstances, short-sighted and fails in its real object.

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* *Bricklaying System.* Chicago, 1909. Clarke Publishing Co.

They approached the subject from a more scientific standpoint, and attempted not to reduce the wages of labour but to increase them, provided that such an increase is accompanied by an increase in output. They did not leave it at this, but by their methods of time and motion study they sought to ascertain how and in what degree real improvement was possible.

The method adopted by them was one that paid considerable attention to the welfare of the worker. Taylor was careful to see that sufficient rest was introduced into the day's work, and Gilbreth has gone further and paid attention to such things as comfortable seating and bench accommodation. In spite of these considerations it is nevertheless true that their systems have caused a good deal of opposition on the part of labour, a fact that gave Taylor great concern. Hoxie* in his report on Scientific Management and Labour and also the Committee appointed by the House of Representatives in its report,† show clearly that in factories working under the Taylor system there is evidence that the workers think they are required to work at a speed which, in the long run, is detrimental to their health. It is significant that the evidence taken from workers by the Committee appointed by the House of Representatives, is to the effect that no real objection is felt to those parts of the Taylor system which deal with systemisation and standardisation, but that strong objection is felt to the methods of stimulation.

This objection to methods of stimulation seems to go to the root of the whole matter, both from the workers' point of view and also from the point of view of those whose approach to the question is one purely of scientific interest.

Whenever a new way of doing work was instituted by either Taylor or Gilbreth a new method of payment accompanied it. The details of the various methods of payment under the Taylor system need not here concern us. The general principle followed is that the actual piece rate should be lowered, but that the task should be so arranged that if the worker comes up to the standard required of him his actual weekly or daily earnings shall be higher than on the old system. The workers believe that under such a system they are induced to work at a speed which is deleterious to their health. It may be possible to continue working at such a speed for several years, but they feel that it takes more out of them than they have a right to give if they are to have regard to their real efficiency as members of society, and not merely as workers in a particular factory. If such a system tends to use up their nervous energy at too great a pace, so that their decline in efficiency begins at an earlier period than would be the case if they worked under a different system, it can be to no one's advantage, except to that of their employer during

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**Scientific Management and Labour*. Hoxie, R. F. New York, 1916. Appleton.

†*Iron Age*, LXXXIX, pp. 726–778.

their most energetic period, that they should work at such a speed.

The issue is confused for those who approach the subject of time and motion study from a theoretical point of view. They are desirous of discovering whether the principles on which the study is founded can be applied to the general problems of industry.

They realise that there is a physiological and psychological background to the whole of human effort, and they want to discover if the methods adopted in time and motion study really go to the root of the matter and indicate more economical ways of utilising human effort. Great improvements in efficiency have been effected by the introduction of new ways of performing certain industrial operations, but whenever these improvements have taken place, there have been two changes, one in method, and one in the system of remuneration, and we are at least entitled to enquire which is the predominating factor.

Workers can certainly be spurred to greater effort by methods of remuneration calculated to penalise the slow worker and reward the quick worker, but such results are of more interest to those who are studying methods of remuneration than to those whose only concern is the fatigue of the worker. Taylor was not studying either systems of remuneration or fatigue; he was primarily concerned with the problem of output, and set himself the task of increasing the production of the various firms in which he worked. He is quite frank on the matter. He says: *" All employees should bear in mind that each shop exists, first, last and all the time, for the purpose of paying dividends to its owners." This is not the place to offer any criticism of such a statement, but anyone holding that view and, at the same time, devoting himself to the problem of production, will clearly use different methods from those who are concerned primarily with the fatigue of the worker.

The above criticism must not be taken to imply an objection to any particular system of payment, or to a change in the method of payment, but only that if we are to obtain data from such systems or such changes, bearing on the problem of increased effort, they should be unaccompanied by any change of method. Similarly, any change of method which is to yield reliable data bearing on the same problem must be unaccompanied by any change in the system of payment.

Both Gilbreth and Taylor make their systems depend primarily upon speed. Taylor always timed the quickest worker, and the standard he set for any task was based on the results thus obtained. It is true that he added a percentage of time to cover unavoidable delays, and also instituted regular rest pauses, but it was speed that he always sought. In no less a degree does Gilbreth make speed his ideal. He regards the quickest movement as the best, and even goes so far as to say that in teaching a new movement, speed must be insisted on from the very first.

* *Shop Management*, p. 143.

He regards it as more important to get speed than to get accuracy of movement or quality of work. His reason for adopting this point of view is that the path a movement follows is different when the movement is done quickly from when it is done slowly. This is, in the main, true, but it may be regarded as doubtful whether, even so, it is wise to insist on speed from the beginning.

Although Taylor was really more concerned with speed than Gilbreth, since he is dealing with time study and not with motion study, yet he does not take up the same attitude of insisting on speed from the beginning. He recognises that the standard may not be reached at first, and that as practice increases the worker will be able to approximate more and more to his highest efficiency.

Experience suggests this was the wiser attitude to adopt, and those who are endeavouring to learn a new set of movements under the Gilbreth system, probably do not actually reach their highest speed until they have become accustomed by practice to the new set of movements.

Apart, however, from the point whether speed should be insisted on from the first in learning a new movement we may doubt whether speed is the best criterion for judging a movement. From Gilbreth's point of view the quickest movement is the best, and so long as speed is the object to be attained this must necessarily be so. It does not, however, follow that the quickest movement is the easiest and the best for the worker to accustom himself to. It may make too great a strain on the nervous system to be advantageously employed by all workers. As has already been pointed out these quick movements are selected from various workers; possibly they may in some way be closely connected with the physical and mental make-up of the worker in question, and their transplantation as isolated motions into the movement system of other workers may be unwise.

Gilbreth gives two definitions of motion study in his book "Applied Motion Study." On page 43, he says: "Motion study consists of dividing work into the most fundamental elements possible; studying these elements separately and in relation to one another; and from these studied elements, when timed, building methods of least waste." On page 202, he says: "Motion study consists of analysing an activity into its smallest possible elements, and from the results synthesising a method of performing the activity that shall be more efficient—the word 'efficient' being used in its highest sense."

Gilbreth makes no distinction between these two definitions, and the only reason for their occurrence seems to be that the book is a collection of papers read by the author before certain Societies, and therefore is somewhat disconnected as a method of presenting the subject.

There is, however, an important difference between the two definitions. In the former "*work*" is the object to which analysis is applied; in the latter it is "*activity.*" Although

these two words may be taken by Gilbreth to mean the same, yet really "*activity*" is a wider term than "*work*" and can be taken to mean not only the operation that a workman performs, but all the physiological and psychological factors that enter into its performance.

If we take "*work*" as the object which is to be studied, we may perhaps content ourselves with finding out the quickest way of doing a task and then saying that that is the best way. The problem is a simple one and the solution is likewise simple. If, on the other hand, we take "*activity*" as being the object which is to be studied, and interpret activity to mean, not something that is done by a worker, but all the physiological and psychological factors that enter into its performance, then we have a very different problem before us. The problem is not merely how to do a particular piece of work in the quickest possible way, but how to do it in the easiest and best way from the point of view of the worker.

Gilbreth does not give any indication that he gives the same content to activity which is here suggested, in fact his whole method seems to indicate that he regards "*activity*" and "*work*" as identical, and sets himself the task of discovering how a particular piece of work can be done in the quickest possible way.

If he had taken any other view, he would not have laid it down that in teaching a new movement, the essential thing was to emphasise from the first the speed at which the movement was to be performed. He would have been more concerned with getting the worker to learn the movement properly and then allowing him to work up to the desired speed as his mind and body became more used to the processes involved. By such a method far less disturbance is experienced than by insisting on a new movement being performed at maximum speed from the first.

§5.—Standardisation.

The standardisation of the human element in industry is the object both Taylor and Gilbreth put before them. The former sought mainly to standardise the time to be taken in performing a task; the latter went further and standardised the method also. It cannot be denied that it would be a great convenience for employers if all human effort could be standardised, especially if that standard was a considerably higher one than they were wont to expect, but in setting this standard the very greatest caution must be exercised.

The method usually adopted has already been described, namely, taking the sum of the constituent elements, plus a certain percentage for unavoidable delays. Only the best workers were timed and it was assumed that if a further percentage of say 33 per cent. were added to this time, then the other workers ought to be able to keep up to it.

In the first place we must consider whether, from the workers' point of view, it is advisable to fix a standard that they are required to reach. It may become a constant source of irritation to them to feel that they must reach a certain standard every hour, or every day as the case may be. On certain days when they are suffering from slight indisposition not sufficient to keep them away from work, it may be wise for them to do less work than they might be able to do if they exerted all their effort. On other days when they are feeling extremely energetic, it may be possible for them to surpass the standard, which if left to their own devices they might do. The thought that they were only expected to keep up to the standard might debar them from putting forth all their energy, lest the standard should again be raised and made more difficult to attain on days when they were not feeling particularly energetic.

Beside these personal factors that might affect the workers' ability to reach the standard, there are those influences which all workers are affected by, though in varying degrees. Among these we must count temperature and weather conditions, and the physical factors that periodically affect women.

With regard to the standardizing of motions, it is doubtful if a set of movements, however good they may be, can necessarily be regarded as the best movements for every person concerned. Personal differences must be allowed for and the possibility admitted of the worker discovering a method better suited to his requirements than the prescribed one. In the majority of cases the standard method may prove the best, but in no case should it be forced upon a worker. Every worker should be taught the standard method and then allowed to follow his own devices, provided the results are satisfactory.

Although there are dangers involved in setting a standard that workers must attain if they are to keep their positions, yet it is possible that the method employed in fixing such standards could, with certain modifications, be profitably employed for fixing piecework rates of pay. In order that this may be properly carried out the very greatest care must be exercised to avoid inaccuracy or unfairness. It will not be sufficient merely to time the fastest worker and then add a certain percentage of time in order to make allowance for those who are not so expert. Workers should be divided into groups either according to age, experience, or some other factor that will assure that all the members of the group have approximately the same initial advantages or disadvantages. If some system of scientific vocational selection could be instituted with this end in view, the problem of setting piece rates by time study would be greatly simplified. In any case where it is proposed to base piece rates on time studies, the results of such studies should be available to the worker as well as the employer, so that the former may realise that full justice is being done to him.

Considerable inequalities in piece rates exist in certain industries, and piece workers often talk of "good" and "bad" work, meaning by the former, work on which the piece rate enables them to earn good wages, and by the latter, work on which the piece rates makes it difficult to do so. A very great deal of trouble is sometimes experienced by those in charge of labour so to apportion the work as to be fair to all concerned. The fact that this is one of the chief duties of the superintendent of a department which works on the piece rate system shows that great inequalities exist in the piece rates assigned. Anything that could do away with this inequality would be welcomed alike by employer and employed, and time study, if properly used, offers an excellent means of solving the difficulty. If such a method of fixing rates were adopted, light would be thrown on many interesting factors.

At present many of the processes necessary to any industry are done by different firms in different ways, and there is little exact knowledge as to the best method of procedure. If all these varying methods were examined, and the results obtained from each made public, a considerable gain would accrue to Industry as a whole. No unfairness would be done to particular firms, for each in turn would profit from the experience of the others.

If such a method were adopted it might be possible to ascertain why rates which seem to yield satisfactory results in one firm are unsatisfactory in another. The inability of the workers in some factories to obtain the same weekly wage as those employed in another factory engaged in the same industry and paying the same piece rate, may be due to no fault of the workers themselves. It may be due to bad arrangements of materials, to unsatisfactory routing system, to noise, ventilation or a multitude of other causes. These factors cannot be remedied until they are discovered, and the best way of discovering them is to submit the factories concerned to a careful examination by a time and motion study expert.

§6. New Point of View in Undertaking Time and Motion Study.

If time and motion study is to be systematically adopted for the industrial concerns of this country, those engaged in it must endeavour to avoid certain errors that have been made in some of the applications to which it has been put. The object for which the work is undertaken must be different, and the type of men employed in the study must likewise be different.

The literature dealing with the subject shows that time and motion study has been left far too much in the hands of those whose main object is the increase of output in some particular industrial concern. This being the case, it is not surprising that the fundamental principles lying at the base

of the study should at times tend to be overlooked, and the attention concentrated on the immediate results to be obtained in the particular factory in which the person carrying on the study is interested. If, however, real advance is to be made along the lines that Taylor and Gilbreth have indicated, the matter must be treated from a broader view point. Improvements in particular factories are not sufficient, however useful these may be, but an endeavour must be made to discover the general principles that govern human effort in industry. So long as the matter is left entirely in the hands of those whose main object is increased production there will be a tendency for the worker to feel, rightly or wrongly, that he is in some way being exploited. If on the other hand he realises that the study is being carried on by those whose only interest is lessened fatigue he will learn to regard the matter in an entirely different light.

Hoxie, in his report on Scientific Management* says that the men he found employed in some of the factories in America for time and motion study were generally poorly paid, with no authority and little power of reasoning. The general practice seems to have been to appoint a superior workman for the task. This means that the worker has another man over him of the foreman type, with little imagination, and the single idea of making the men work. If this type of man is to be employed, in what after all is a most delicate operation, we can hardly wonder if the results are crude and unscientific. We cannot expect that a man of this type will be able to undertake the work from a scientific point of view, and realise how complicated the problem is. The most that we can expect is that he will be able to devise a quicker way of doing the work regardless of any physiological or psychological principles that may underlie it. Moreover, this type of man can have no authority with the management, as Hoxie points out, so that any recommendations from him will be treated in the same way as recommendations from similar men of his grade. This means that the management may override parts of his recommended system, adopting only such parts as are considered commercially profitable. In so doing the whole nature of the system may be changed. Schemes cannot be suggested here for getting over difficulties of this kind, but all who have an unbiased interest in the subject will agree that if this work is to be undertaken in a factory it must be entrusted to those who realise the very delicate nature of the problems they are handling and have sufficient training and ability to appreciate the many complicating factors affecting it. Moreover, some system must be devised which enables the workers to fully understand what is being done so that they may co-operate in the undertaking, and not feel that something they neither understand nor approve is being forced upon them.

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* *Scientific Management and Labour*, p. 56.

Having indicated the point of view from which time and motion study should be carried out, and the type of man that should undertake the task, we may now go on to consider the principles that should guide the actual prosecution of investigations.

Before motion study proper can be undertaken certain preliminary investigations have to be made, and the first of these is that of unproductive labour. In almost all industrial operations that have not been regulated according to a well thought out plan, a considerable amount of time is wasted by the skilled worker in purely unproductive labour. It may take many forms. The skilled worker may be required to fetch the materials he is to work on, or to remove them when he has finished them. He may be required to prepare the tools he is to use, or to perform some operation subsidiary to the main work in hand. Such unproductive labour may not, in itself, be a bad thing, since it may provide a rest for muscles that are continually strained in the main operation on which he is employed, and in so far as this is the case and such rest cannot be conveniently provided otherwise, it is undesirable to have this work done by a less skilled worker. Whether such interruptions in the work are advantageous or not will depend very largely on the nature of the work, and the amount of energy put forth in performing the tasks that act as interruptions to the main occupation, and this can only be determined by actual experiment. Besides actual labour that a worker may be required to do on jobs subsidiary to his main purpose, he may be kept waiting from time to time on account of the method of supply. Whether this enforced rest is beneficial or not is also a matter for experiment, and must be governed by such factors as regularity and duration of the pauses.

In certain types of work, arranging for rest pauses in a convenient way may be difficult, and if it is found desirable that rest pauses should be part of the system of work, they may possibly be best introduced by limiting the supply in some way at regular intervals. The danger of all such methods of regulating the work is that the enforced rest periods tend to be irregular in length and occurrence which may cause irritation to the workers. There is considerable difference between the mental state of the man who is kept waiting for an indefinite period, and that of the man who is given a definite period of rest. The former may cause irritation and thus defeat its aim as a rest pause. If this is found to be the case, some other and more congenial method should be discovered in which the rest pauses may be introduced.

Another way of reducing unproductive labour is by more accurately adjusting the apparatus necessary for an industrial operation to the requirements of the worker. There is very rarely any definite reason for the size of the apparatus used, other than a tradition, the foundations of which are obscure. In

some cases certain of the arrangements made for the performance of an industrial operation are certainly not well adapted to the workers' needs, and cause him unnecessary labour. In some accounts of improvements that have been carried out, instances will be found in which much unproductive labour was saved by such simple devices as supplying a bench on which to put the articles to be worked on, instead of requiring the worker to take them from the floor. The improvements that can be effected in this way range from such simple alterations as these to those depending on intricate mathematical calculations. Whether such simple devices as providing benches should be regarded as belonging to the subject matter of time and motion study is doubtful. In many of the cases to be found in the literature on the subject, no pretence is made that the right shape of the benches or trolleys in question were the result of anything other than common sense. The work that Taylor did in order to discover the right size of a shovel is of an entirely different order. So also are the extremely elaborate experiments he carried out to determine the right speed and right type of cutting tool to be used on any particular lathe operation. Such work is highly ingenious and a first-class contribution to the science of industry.

Similar work to this may be carried out in most industrial operations. It may be of a simple nature as already indicated, but in a well-organised factory such elementary improvements have already been effected by the management, and any alteration will have to take the form of determining from careful timing observations the best size and shape of the articles of which the worker makes use. The right size of tray may make a considerable difference to the worker. If it is too large fatigue will be caused by having to reach too far to utilise all the space available, and if the article to be carried on it is heavy it may cause unnecessary fatigue. If the tray is too small, fatigue will be caused by having to empty it too often. The same principle applies to the size and arrangement of the bench. If it is too small and compact, it will cause the worker to feel "hemmed in"—to use a factory expression, and if it is too roomy it will cause the worker too much fatigue to reach for the various articles necessary to the operation.

A determination of the right size of industrial apparatus is comparable to the determination of the right distribution of rest pauses. The one endeavours to find the most economic spatial relations; the other seeks to discover the most economic temporal relations.

When everything that is possible has been done to reduce the unproductive labour of the worker, or to use it as a means of relaxing the muscles most liable to fatigue, the next thing is to consider the general conditions affecting the comfort or discomfort of those whose operations are being studied.

The first thing to be considered is how far an operation that is usually done standing can be equally well done sitting, and how

far an operation that is done sitting can be equally well done standing. The body is sure to become unnecessarily tired if it remains the whole day in one position, either sitting or standing. If the operation cannot be done in both positions, sitting is preferable to standing, but it is only the lesser of two evils.

Many attempts have been made to provide sitting accommodation during working hours, and a great number of these have been declared useless both by the worker and the employer. It is not uncommon to find a stool of uncomfortable size and shape provided for use at the same bench which has previously been used to work at while standing.

The result is increased discomfort for the worker. Such benches were never meant to sit at and so have been constructed in such a way as to leave little or no room for the legs. The blood supply to the legs is generally cut off, either by the legs hanging over the sharp edge of the stool, or by their being pressed against the supporting ledge of the bench, and in many cases the legs of the worker are required to suffer both disadvantages. When sitting on such a stool at such a bench it is generally impossible for the worker to get near the work engaged upon, except by bending forward in an unnecessarily uncomfortable position which puts undue strain on the muscles of the back.

Too much care cannot be expended in devising really proper sitting accommodation. A comfortable and sufficiently large seat, though not too large to hamper the movements of the worker, is the first requisite. This should, if possible, be properly shaped and padded. Adequate room should be allowed for the legs so that their position can be changed from time to time, and proper foot-rests should also be provided. Each worker should be provided, not with a standard stool, but with one exactly the right height to correspond with the sitting height of the body.* This seat must be constantly changed in the case of the young to provide for growth. Such careful adjustments may be thought by some to be unnecessary, but they might be induced to change their opinion if they were to sit for a whole day on one of the stools of the type generally to be found in factories, and required to work at a bench that was intended originally only for those who were standing during working hours.

In all the cases which have come under the writer's notice in which proper seats have been provided for the worker, the results have been satisfactory. The worker has always used and appreciated them, and their fatigue, as measured by increased output, has always been lessened. The general tendency seems to be for the workers to stand at their work during the early part of the morning and afternoon, and to sit for the latter part of both periods. They also use the seats more during hot weather

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* This can be arranged by providing an adjustable seat. Also see Home Office Welfare Memorandum, No. 6 (*Seats for Workers in Factories and Workshops*).

than during cold. Workers who have been used to standing during the whole day for many years say that the muscles of the legs suffer from "cramp" during protracted sitting, and they are generally somewhat averse to using the seats provided. This is not so with young workers. They are only too anxious to use the seats that are provided. For this reason it is generally better to provide the younger workers with seats first, and the older workers, seeing the use the others are making of the seats, will most probably ask to have similar arrangements provided for them. In no case should any worker be forced to sit or stand where an operation can be done in either position, the choice being left entirely to them, but beneficial results from a change of posture can only, in the first place, be looked for in those workers who have not become too used to the old method.

Other factors that must be carefully considered are lighting and ventilation. It is not possible to deal with them satisfactorily in an account which concerns itself only with time and motion study, for they are really separate subjects and can only be adequately dealt with in a treatise entirely devoted to them. They cannot, however, be left out of consideration by those engaged in time and motion study.

In such a study everything that affects the worker must be taken into account, and an investigator must be constantly on the look out for any possible causes of irritation. These need not necessarily be dealt with by him, but can be handed on to experts on such matters. His concern is that they should be scientifically dealt with and that everything possible should be done to provide a healthy atmosphere and adequate lighting

§7. Motion Study Proper.

In the definition already given of motion study, it was said that it seeks to eliminate unnecessary movements and to improve the necessary ones. This may be taken as a general definition, which will include various methods of improvement. What is meant by improvement must be understood before we are able to pass judgment on the desirability of motion study.

If speed is the object sought, the value of any movement must be judged by its speed. There may, however, be another standard by which movements can be judged, namely that of the ease with which the worker can perform the movement in question. Those who take this view will dismiss the speed factor entirely from their minds. They will endeavour only to devise some method of doing the task in question, which shall be more in accord with physiological and psychological laws, and that will utilise the natural aptitudes of the worker in a more efficient way. Those working on this principle will not seek to discover how quickly a worker can perform a task, but will endeavour to arrange that the task may be done in such a way as to interfere

in the least possible degree with the worker's rhythm. The effort of the worker will become the centre of attention and not the task.

There is no doubt in the writer's mind that this latter method of carrying on motion study is likely to yield more beneficial results than the former. It is undoubtedly more difficult, but it has the advantage of resting on principles which are of general application. So long as those interested in motion study are content merely to improve specific industrial operations no very important principles governing the general problems of the human factor in industry are likely to be evolved, but when the attention is directed to the more fundamental aspects of the problem, specific instances of improvement merely act as examples of the manifestation of a principle that can be applied to other industrial processes falling within a certain sphere of human activity.

If this principle is adopted the question arises how are we to know if improvement has taken place by the introduction of a new set of movements. The method usually adopted, as has already been pointed out, is to accompany the introduction of a new system of movements with a carefully devised method of payment calculated to stimulate increased effort and to penalise any falling away from the standard that has been set. If under this system increased output is effected it is regarded as an indication that the system of movements introduced causes less fatigue to the worker than those that were superseded. This may or may not be the case.

Possibly, and in some cases probably, the new method of payment or some other device calculated to speed up the work plays a far greater part in the general increase of output than the newly devised system of movements. So long as improved methods are invariably connected with new systems of payment we shall be unable to judge with accuracy as to the merits of those movements.

Even if the introduction of the new movements is not connected with any new system of payment, those who adopt the point of view of motion study suggested cannot be satisfied simply with an increased output. Increased output is extraneous to the main issues, and therefore cannot be looked upon as the sole criterion of success. At present there is no very reliable measure of fatigue that can be applied under factory conditions, and until such a measure is discovered we must content ourselves by judging the success of a new system of movements in the following way.

The essential features of the new method should be, first, that it is more in accordance with physiological and psychological laws, so that the body and mind are used in the most economic way by avoiding all possible strain of the muscles and nervous system. Secondly, the new method should meet with the approval of the workers who have given it a fair trial and should have the result of making them feel less tired and

more satisfied with their work. If these requirements are fulfilled then the result may be regarded as satisfactory.

An increased output may or may not result. This will depend on how much improvement has been effected. If it is sufficiently large to allow the body to do more work without any external incentive, such as higher monetary rewards or dismissal if a certain standard is not reached, then greater output, if the same hours are worked, will be the natural result. If shorter hours of work are adopted, then the result may take the form of doing the same amount of work as was previously done in the longer hours. If the improvement is not so great the only result will be that the worker is less tired after the day's work than he was before. The inability to make so large an improvement as to affect output under the conditions laid-down, must in no way be attributed to the experimenter or the worker. The nature of the work may be such that an appreciable improvement affecting output is impossible, either because the work is so fatiguing that the body soon reaches its limit under any system, or because the sphere in which motion study can be applied is too small.

In all cases that have come to the writer's notice, where the principle suggested has been the basis of a new set of movements, increase of output and increase of earnings has actually taken place, though in no case was any effort made to get the workers to increase their effort.

Nothing that has been said must be taken as indicating that improvements effected by those working with the former of the two principles in mind, are not sometimes the same as those that would be suggested by experimenters who have only the latter principle in mind. Often the quickest movement is the best movement from every point of view, but it need not necessarily be so. The only reason for the previous discussion is to suggest that, perhaps, a more fruitful development of motion study may be expected by concentrating on the fundamental principles at issue, rather than on the immediate gains that may result.

The ease with which work is done with a method of scientifically studied movements (as compared with the same work being done with a system of movements that have not been so studied), can be seen if a visit is paid to two groups of workers doing the same type of work, the one with improved movements and the other on the old system. The former will appear to be working slower than the latter and in fact will be doing less work. They are indeed doing less work, but they will in almost every case be producing more of the finished article on the manufacture of which they are engaged, and if they are on the same piece rate as the other workers they will naturally be earning more money.

A good deal of unnecessary fatigue is caused by concentrating the worker's attention on speed and not on the work in hand. If this is done the tendency will be for the worker to work at such

a rate that the movements employed will become too numerous or too extensive in nature. If the feeling is allowed to grow up in the mind that every operation must be done as quickly as possible the worker will be apt to think that speed in itself is desirable, and will pay attention primarily to that factor instead of to the work to be done, which alone should occupy the mind. Many of the unnecessary movements which are now found to be part of almost all industrial processes, may be due to a desire, on the part of the workers at least to look as if they are working hard, or may be due to a real endeavour to work hard, which has only resulted in more effort being put forth causing increased fatigue but not increased production. The traditional methods of overseeing are undoubtedly responsible for much of this evil. It has been regarded as the function of the management to see that everybody in the factory works hard; it has not been regarded as part of their function to see that everybody works easily. In any room where there is hurry and flurry on the part of the workers, one may be safe in assuming that there is less real result than in a room where the workers are so much at their ease that they appear not to be putting forth their fullest effort.

§8. RHYTHM.

In most industrial processes there is a set of movements which is strictly necessary for the performance of the work; there is another set which is made necessary by the bad arrangement of materials or the inexperience of the workers, and there is a third set which can only be accounted for by assuming that it represents the rhythm to which the worker has become used. The first set of movements cannot be done away with as long as the work remains essentially the same, but it can be altered by intensive motion study. The second set of movements can be entirely eliminated or altered by what has been described as extensive motion study, but the third set is the most difficult to deal with, and also the most necessary to deal with if the fatigue of the worker is to be the real concern of the investigator.

These three sets of movements are not really separate, but together form a set of movements which has become traditional in the performance of any industrial process. Some difficulty may be experienced in determining to which group any particular movement belongs, but if the matter is to be properly taken in hand the attempt has at least to be made. When the unnecessary movements have been eliminated by extensive motion study and the necessary movements improved by intensive motion study, the experimenter must consider how far the remaining movements, due to the sense of rhythm in the worker, are necessary, and how far they can be modified and improved.

The first thing to be noticed about these movements is that they differ for each worker. A general similarity will be

found in all of them, and this may perhaps be taken as an indication of the type of movement that is necessary in any particular work if the body is to work in the easiest manner, but although the movements are to some degree similar, very great differences will be found between workers. Some will indulge to a greater extent in this type of movement than others, and some although making the same or a lesser number of the movements, may make the movements themselves greater in extent than others who are actually making more movements. If the workers are questioned as to these movements they will almost invariably say they are necessary, giving all sorts of ingenious reasons for their assertion. In some cases this may be true. For instance, a certain amount of time may have to elapse in each set of movements in order that the article being worked on may cool, or have time to react in some other way. If this is so, it may be best for such minute fractions of time to be measured by the rhythmic beating of the hand in some way that the worker has found fairly satisfactory. In spite of this the experimenter will do well to doubt all assertions about the necessity of certain movements made to him either by the management or the worker, and only accept such movements as necessary where he has proved them to be so by his own experience.

Having decided what movements are absolutely necessary for the performance of the task, the next question will be to consider what extra rhythmic movements may be allowed in order that the worker may feel quite at ease. The ideal is to make the necessary movements so rhythmic and graceful that no extra movements need be put in so as to appeal to the worker's sense of rhythm. It will be generally found that workers who have had long experience at a particular type of work, have developed a great number of unnecessary rhythmic movements which it may be difficult for them to give up. In fact it is very doubtful if attempts should ever be made to get workers who have become accustomed for many years to one set of movements to relinquish them in favour of another set. The movements have become semi-automatic and great discomfort is caused in any attempt to break so well a formed habit. With beginners it is different. If they are taught a graceful and rhythmic set of movements from the beginning they will form habits of work which, when once formed, will be difficult to give up, but if they are based on scientific time and motion study, they will enable the worker to work so much more easily than under the old system that presumably there will be no necessity for them to be given up.

In most cases if the improved set of motions is of a really rhythmic character, there will be no tendency to superimpose other rhythmic motions on it. A superimposed rhythmic movement is one that is not actually necessary to the performance of the task. but which is introduced by the worker, either because

motor control is weak, or because the ordinary movement involved in doing the task is of such a kind as to give no pleasure in its performance; in this latter case another movement is introduced in order to compensate for the tiring effect of the necessary movement. Possibly these movements are introduced in order to synchronise with some physiological rhythm whether of muscular contraction, heart beat or breathing, but whatever their cause these movements should not, unless they are having markedly bad results, be objected to. Some workers have a far greater power of motor control than others, so that their rhythmical movements are far less extensive, or to use a trade expression " they throw themselves about less " than those whose power of motor control is not so highly developed. This is fortunate for them, but there is no justification for endeavouring to make those whose motor control is weak adhere to the smaller movements of those whose motor control is strong. In the circular movements adopted in sweet covering individual differences are found between workers doing the same set of movements. Some find it necessary to make longer circular movements than others, although all are doing the same type of rhythmic movements.*

Besides the individual differences already mentioned, there is always a tendency when working quickly to make longer rhythmic movements than when working slowly. On the whole the better workers do so less than the others, and although this may in their own interests be pointed out to those who tend to develop wide movements, that is no reason for forcing them to attempt to modify them, which they may not be able to do.

A distinction must be made between those who are using the rhythmic method of working and yet find it necessary to make longer movements than others, and those who in an attempt to "hustle" drop the rhythmic method for some haphazard method of their own to which they will invariably add some unnecessary rhythmic movement. Workers left to themselves probably tend to beat to an unnecessarily lengthy and complicated rhythm, and this may be the cause of many of the unnecessary movements that are to be found in most industrial processes. This is certainly the experience in sport where motion study has been undertaken more scientifically and with greater success than in any other activity.

The sense of rhythm must be allowed for, and should form the basis of any scientific system of movements, but naturally no rules can be laid down with regard to it. The object an experimenter should place before him is to devise a set of movements that will do the work properly, and at the same time be able to set up rhythmic motor habits in the worker. One movement should follow on naturally from the one preceding it, and the terminal phase of the preceding movement should naturally suggest the initial phase of the next movement.

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* See p. 26.

Mental associations will be formed for any set of movements that has become habitual to the worker, but if when the terminal phase of one movement suggests the initial phase of the next to the mind, the hand should be in a position not well adapted to carry out the movement, irritation will be caused. The worker knows what is wanted, but attention has to be taken off the main object for a moment in order to direct the movement of the hand in the right direction. In a well thought out system of movements this should not be the case. The mental associations and the tendon and joint associations should run along parallel lines, and one should never be broken by the other.

In playing golf there are certain mental associations formed as to the right stroke to play on each occasion, but, paying attention to these, will almost invariably cause a bad stroke to be played. Through careful teaching and practice certain muscle and joint associations—generally called muscle memories—have been formed, and to these the player must pay attention if he is to play the proper stroke. So also in industry the mind should concern itself solely with the object to be obtained, and wield only a general directing influence over the actual movements involved. The movements themselves should follow one another in a natural sequence. If the movements have been carefully thought out according to the plan suggested, they will follow in a rhythmic order that causes the least possible strain to the body and the least possible interference with the mind. When one process in the task is finished it will naturally suggest the one that is to follow, and then the hand should find itself in the best possible position for doing the work required, without any volitional change of direction. Every effort must be made to save the worker as much cognitive and volitional effort as possible, and attention should not be confined merely to saving physical effort.

A large field of research lies open along these lines. At present very little is known about rhythm in industrial processes, although it can be seen how large a part it must play. However much a method of doing work may be improved, there are always variations in the effect it has on different individuals. The average of output may be raised, but the variation about that average remains the same. This variation may be due to many causes. Rhythm and motor control probably play a large part in it, and it may also be in some way affected by varying types of fatiguability. Research into these problems would be of great service to those who are interested in the subject of time and motion study.

§9.—Time Study.

Time study as employed by Taylor was primarily a method for determining how long should be allowed for the performance of a task, and was the essential part of his system of standardisation. Gilbreth uses it for the same purpose, but he goes

rather further than Taylor, inasmuch as he not only times movements in order to ascertain the standard time, but also in order to compare the time taken by one movement with that taken by a similar movement performed by a different worker. This is an important part of his method, because he assumes that the best movement is the one that takes the shortest time, so that he is obliged to time various movements in order to determine which is the best.

When time study is used solely for determining the time a task should take, it seems very unlikely that it will yield satisfactory results. In the first place, if the worker knows that he is being timed in order to set a standard time he will naturally tend to slacken his pace, so that too great a task may not be required of him later on. Taylor got over, or thought he got over, this difficulty by selecting a special worker and stimulating him to increased effort by increased remuneration. Gilbreth employs the same method. The result is that the time of the best worker is obtained when he is working under abnormal conditions, which increases his speed. Even if a deduction is made from this time for the average worker, injustice may possibly be done to the slower workers.

Generally, in any department there is one, or sometimes two or three workers whose output is far in advance of the average of the good workers in the department. In some cases this advance may amount to over 100 per cent. If this worker then is timed and a deduction of, say, 33 per cent. made from the time, it still leaves the task of the others 66 per cent. harder than it should be. If it is still further reduced so as to fall into line with the average worker, there is no point in having taken the timings in the first instance. If time study is to be used in this way it can only be used in order to speed up those who do not reach the standard of the best workers in a department.

If all workers were equal psychologically and physiologically, it might be assumed that if certain of them continually failed to come up to standard, it was due to laziness or some other moral fault. But there is no reason for thinking that all workers are equal. In fact there is every reason for thinking that they are not. Before any such use of time study as that made by Taylor and Gilbreth can be adopted, further progress must be made in vocational selection. If it were found possible to group people together in such a way as to do away as far as possible with the inequalities which, at present, exist between worker and worker, it might then be found possible scientifically to apply time study for the fixing of standard times and standard rates of pay. At present, however, we are very far from such a state and nothing but harm can come from any attempt to standardise work by means of a stop watch.

The proper use of time study under existing conditions is to time each element involved in an operation in order to see which are the processes that are taking most time to perform. To

these we should apply our attention in the first place. If time study is used in this way, it will reveal how much time is being spent on unproductive labour, and how much of the work put into a process by the worker really counts towards the production of the article to be manufactured.

In any re-arrangement of the work the exact time taken by each process must be known in order that the relative time value of the processes may be accurately determined. Unless we are in possession of such details any re-arrangement of work which depends upon co-operation between workers would depend entirely upon hazard, instead of upon accurate knowledge. In the taking of such timings, there is no necessity to time only the best workers, or to stimulate them to work at an unnatural speed. The relative times of all processes will stand in the same relation in all workers if we allow a certain margin for individual peculiarities.

There seems, therefore, very little necessity for all the elaborate apparatus that Gilbreth employs to determine the time and direction of movements. They are necessary for his system for reasons already explained, but they are not necessary for a system founded upon the assumption that those motions are the best which are most in accord with the psychological and physiological make-up of the individual. Cyclegraphs are certainly useful for determining the path followed by the hand or foot, but the time element in them is of no great importance. For instance, a set of motions might be devised which actually took longer to perform than the set to be superseded but which gave less fatigue to the worker, and so enabled him to perform them more often and more regularly. Such points as these, however, cannot be ascertained by the timing methods devised by Gilbreth. The idea of time should be dismissed from the experimenter's mind, except for the purposes already mentioned, and he should concentrate on getting an even and graceful movement that will do the work effectively. The fast stroke does not always win a rowing race ; far more often the slow stroke is more effective, and, generally, such a system is more effective because it is slow and allows for plenty of time to recuperate between each effort. So it must also be in industry. No movement can be compared with another and said to be better than it merely on account of its speed, it should only be compared in respect to ease and final results.

What has been said here about the impossibility of properly fixing rates on the time basis only may be thought to be in contradiction to what was said on the matter in the section on standardisation. If an expert is to be called upon to give advice as to the proper rate of pay in an industry, such advice will be based on other factors than time study. Time study will certainly enter into the calculation of the proper rate of pay, but it must never be regarded as in itself a determining factor. It must be used, as has been suggested, to find out where time

is lost so that a proper study of the causes of such waste of time may be undertaken. Any such method of arriving at the proper rate of pay will be based on such varying conditions as lighting, routing, physical conditions of average worker, etc., and not upon the time of the best worker plus 33 per cent.

There are many other objects to which time study can be profitably put. It may be used to test the efficiency of machinery, as Taylor did when experimenting on lathes. Whether a process is better done by hand or by machine (and the latter is not always the quickest), or whether by using a machine of one type or another, may be determined by this method. By time study observations we may discover which are the processes in a machine that cause loss of time and need the engineer's attention.

Time study is useful for testing methods of routing and management. Surprising results sometimes come to light when a worker, or group of workers, is timed in order to see how much time is wasted by inefficient management and faulty organisation. In some factories the custom prevails for those whose duty it is to inspect the finished articles to take each one that does not come up to the standard back to the worker at fault, and not only request that the fault should be made good, but express disapproval at its occurrence. Such a method may waste a considerable amount of the worker's time; not only is work discontinued in order to listen to the inspector, but the rate at which work is performed after the interference may be considerably less than before. This slackening of the speed is in no sense due to the worker's will, but is caused by an interruption of working rhythm or by a slight mental disturbance set up on account of the disapprobation expressed by the overseer. Naturally no rule can be laid down in a matter of this kind, but it may well be worth while to have a process time studied, not to find out anything connected with the worker's movements, but merely to determine how much of the worker's time is wasted by the management.

Time study can also be used for testing the efficiency of light, or temperature regulation. Output records may be taken during certain hours of the day or under different lighting conditions and the results compared,* or more definite experiments with specially lighted chambers can be undertaken. In the latter method careful individual time studies could be made, and it could be discovered which processes, if any, were improved by certain changes in illumination. By this method the most economic standard of illumination could be discovered for the particular operation in question.

Time study may also under certain circumstances be used for testing fatigue at various periods of the working day, and the results thus obtained will yield suggestions with regard to the introduction of rest pauses.

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* ELTON, P. M. (1920): "A study of output in silk weaving during the winter months," *Industrial Fatigue Research Board Report No.* **9**.

§10. Conclusion.

The conclusions to which a consideration of this report would lead may be summed up under the following heads :—

1. All time and motion study must be undertaken solely in the interests of lessened fatigue and never in the interests of increased production. When a proper system is carried out, increased production will probably result, and in all cases which have come under the writer's notice has actually taken place ; but if increased production is made the object of the experiment the true issue becomes confused, and what purports to be a scientific investigation degenerates into a process of speeding up.
2. The underlying principle of motion study is rhythm and not speed. We must look upon the best set of movements as the easiest set and not the quickest set.
3. The proper use of time study is for the analysis of an operation in order to suggest lines of improvement, or to determine the relation between processes, rather than for standardisation. The setting of a standard tends to introduce an interfering element in the worker's mind. All the effort of the investigator should be concentrated on lessening fatigue and increasing the ease with which the operation can be performed ; other things being equal, the operatives will set their own standard, which will be satisfactory to all concerned.
4. Time and motion study is only part of a whole region of study affecting the human element in industry, and can only be carried out in conjunction with the study of other equally fundamental problems.

The first three points need no further comment ; sufficient has been said in the main part of the report to indicate the reasons for regarding them as lying at the base of a proper system of time and motion study. A short consideration of the fourth point will make clear why it has been added to the others.

Any one undertaking time and motion study will be brought into close contact with many other problems, a satisfactory solution of which must be found if his own problem is to receive adequate treatment. The most prominent of these is incentive. This is recognised by Taylor and Gilbreth, and is the reason they always accompany their methods with particular systems of payment calculated to give a strong incentive to the worker. The only incentive to which the worker will respond is generally assumed to be that of money. Any increase of output resulting from a change of system in which the co-operation of the worker has been a factor making for success should certainly carry with it an increase of pay. This, however, is not the system adopted in America. The workers are not given the full increase to which they are really entitled, but a scheme is introduced calculated to

increase the speed of the worker while at the same time giving him only a small percentage of the real increase of output. Such a system is open to two objections.

First, the worker's opposition to the whole system is aroused by his not being paid what he considers his full share of the increase, and, secondly, the new system of payment is always introduced in conjunction with the new method of doing the work. The first is wrong in principle, and the second confuses the issue as to the benefits derived from time and motion study.

Besides the scientific study of incentive which is necessary if we are to go far in the direction of improving industry by means of time and motion study, there are other factors which play a no less important part in the general study. Rest pauses, vocational selection, monotony, systems of management, hours of work, types of fatiguability, rhythm, motor control, are among some of the factors which affect time and motion study very considerably. Independent investigations should be carried out on these subjects and the data obtained from such enquiries could be introduced into time and motion experiments and the results carefully noted.

PART II.—EXAMPLES OF MOTION STUDY.

§1.—Introduction.

A perusal of the literature dealing with time and motion study reveals certain main principles that underlie all the experiments hitherto undertaken. The experiments themselves have differed, and the results have varied, but the general methods have always been the same.

Time study has been used first to determine the maximum time necessary for each unit of work, and then from these data to fix a standard time for the whole task.

Motion study has been used in conjunction with time study. The movements which take the shortest time to perform have been discovered, and unnecessary movements have been eliminated. A standard method of doing the work has been established, and a standard time fixed for its performance. Speed has been the criterion by which results have been judged. A quicker method of doing a task has been assumed to be also a better method. In order to assure speed, increased remuneration has invariably accompanied the introduction of a new method of work. The methods of payment are varied but the underlying principles are similar. The worker is not given a pro rata increase of pay with an increase of output. His work is so arranged that an increased output carries with it increased earnings in a definitely lower ratio. If he reaches the standard set he will earn more than on the old system, and the possibility of doing so acts as an incentive to increased effort.

The following experiments were carried out on somewhat different principles.

Time study was used to determine the time certain operations took to perform, and the time relation in which one operation stood to another. It was never used to set a standard time.

Motion study was used, not in order to determine which were the movements that took the shortest time to perform, but to discover those movements which, when properly learnt, the worker would find easiest to perform. The ease with which a movement could be performed was regarded as more important than the shortness of the path followed or the time taken.

No attempt was made to standardise the time taken or the method of doing work. Instruction was given in a new method and the workers were then left to decide whether they adopted it. Instead of fixing a standard method which partakes of the nature of a set of rules to which the worker must adapt himself, an endeavour was made to discover a method of work which would be more in accordance with the worker's natural rhythm. The standpoint was subjective rather than objective.

No attempt was made to increase output or to encourage the workers to put forth more effort. No change was made in the method of pay, except in one case where a change was necessitated by adopting team work. In this case the workers devised their own method of pay, after they had given the system a fair trial.

The object of these experiments was to see if an alteration in the method of working based upon physiological and psychological principles would have satisfactory results apart from any external influences such as standardisation or special methods of remuneration.

§2.—An Experiment in Sweet Dipping.

The process of "dipping" consists of putting a centre (an almond, walnut, Brazil nut, or caramel) in a basin of melted sugar with the left hand, and covering it with the sugar by working it with a fork held in the right hand, and then placing the finished sweet on a tray. The process is carried on entirely by girls, and is one of the most elementary forms of piecework, requiring comparatively little skill to perform, though if high wages are to be earned considerable dexterity must be acquired. The process is of a monotonous and fatiguing nature, as the girls stand over a basin of sugar, kept hot by means of a gas jet, and repeat the operation 22,400 times a week in the case of a fairly good worker doing about 550 lb. per week. The working hours are from 7.30 to 12.30 and from 1.30 to 5.30, with intervals of half an hour in the morning and half an hour in the afternoon for tea. On alternate Saturdays no work is done, half a day's work being done on the other Saturdays.

In spite of the fact that the process of dipping is a comparatively simple one, where quickness is more essential than skill, yet one of the first things noticed by the investigator was that output stood in direct relation to age and length of employment. Most of the younger girls seemed to be experimenting in different ways of doing the work and even among the more experienced workers considerable divergence of method existed. The fact that it took several years' practice to attain full proficiency may be due either to fatigue being felt more acutely by the younger workers, or to their inability to acquire the necessary motor habits to perform the task with ease. From the result of subsequent experiments it would appear that the latter factor played a considerable part in accounting for their relatively low output.

Work was commenced by careful observations on one of the more proficient workers, who was placed at the disposal of the investigator and willingly co-operated with him in his experiments.

The first problem to be solved was that of unproductive labour. It was found over a lengthy period of observations that 21 per cent. of the total working time was spent in unproductive labour. This unproductive labour was to be accounted for in two ways :—(1) the worker having to leave the bench in order to empty trays and fetch fresh supplies of centres, and (2) by replacing full trays by empty ones while still at the bench.

In order to reduce the time wasted in emptying and fetching trays, a system was started whereby a time worker waited upon the best eight workers of the department. The results, however, were not satisfactory, partly on account of the fact that a certain amount of the "dipper's" time was wasted by her being disturbed while the other worker removed or replaced trays, and partly also from the fact that the leaving of the bench at regular intervals probably helped to lessen the feeling of fatigue and monotony. Five-minute rest pauses were also introduced each hour, but these, too, were discontinued at the workers' request, as they were felt to be more bother than they were worth. It must be remembered that they already had breaks in the middle of the morning and afternoon for refreshment. The output during both these experiments remained practically the same.

The second factor causing unproductive labour, namely, the replacing of full trays by empty ones while still standing at the bench, was then taken in hand. Calculations were made from the length of the worker's arm and the size of the bench, and a new tray was ordered of a larger size, and it was also arranged that each worker should have a larger number of trays at her disposal. This resulted in reducing the unproductive labour from 21 per cent. to 7·44 per cent., and the new tray found great favour with the workers. On one occasion when a new set of trays was ordered a mistake was made and the

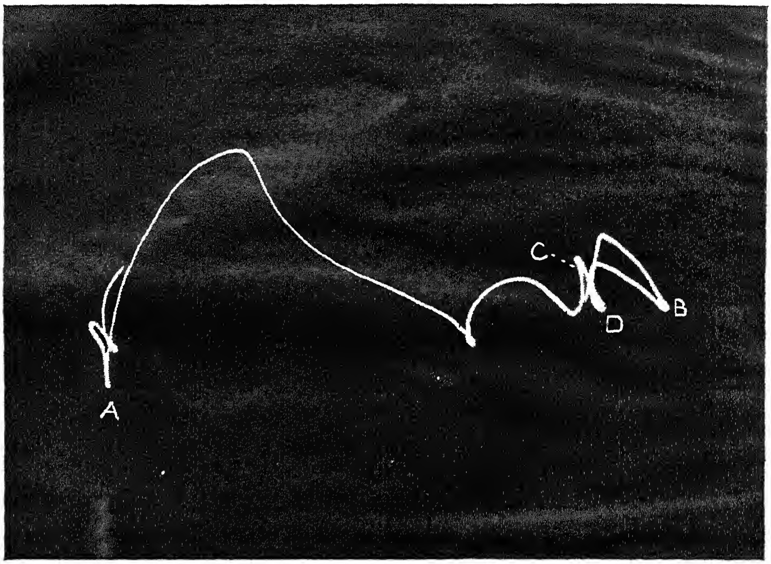
trays supplied were of the original size. This was quickly noted by the workers and a request was made that trays of the new size should be supplied, which was, of course, acceded to.

Irritation was felt by the workers because they had to wait at times for fresh supplies of sugar. The reason for this was that it was thought that if a small interval of time took place between each fresh supply, it afforded a rest for the dippers. Though the intention was good, it defeated its own end by the workers feeling that they were being kept waiting, and not that they were being given a rest. When new arrangements were made for a more regular supply of sugar, the average increase in the output of each worker in the Department was 1·31 lb. per hour, and since the workers were on piecework, this meant a corresponding increase in their earnings.

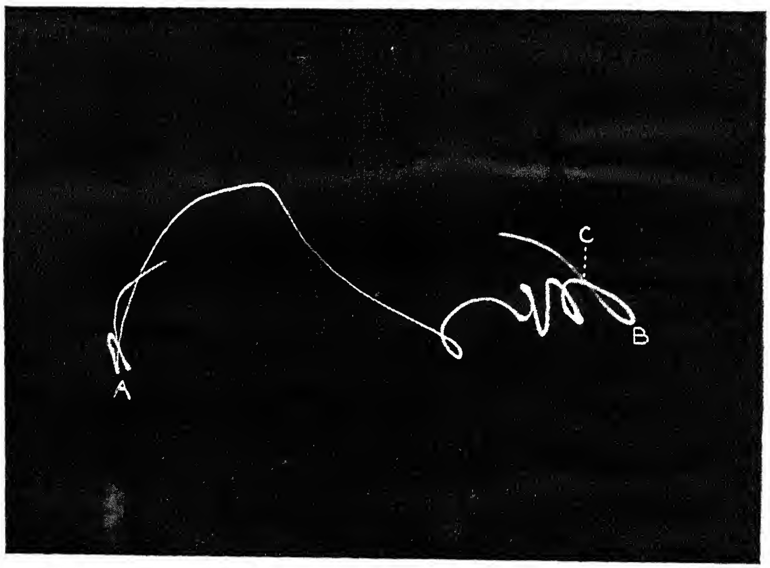
An interesting little experiment was carried out by the Investigator and the worker who was co-operating with him in order to test how much output could be increased merely by speeding up. It was arranged that she should work at the greatest speed possible for a few hours and her output during that period measured with her output during normal working hours. Her output increased 105 per cent., but she was so exhausted at the end of the experiment that she asked that it might not be tried again, saying it would kill her to work like that. Under certain applications of the Taylor System in America this girl would have been kept by hourly encouragement at the pace she had once reached, in spite of the fact that she proposed to forgo any increased remuneration that might result from increased output. It is to be hoped that the experiment this girl so kindly co-operated in may do something to prevent any attempt to increase output merely by increased effort, and stimulation, calculated to keep that effort always at its maximum. The pace at which workers find it best to work should be the pace at which they should be allowed to work, and any increase of output must be looked for from improvement of method and not from increase of effort.

It was found in discussing matters with the workers that one of the things that irritated them was the constant feeling that they might touch the worker next to them with their arm or upset her tray, and also that they felt tired through having to stand all day. Attempts were therefore made to devise a type of bench giving the worker more space and making the work possible while sitting. Such a bench was constructed, but it was not found possible to introduce it into the room where work was originally started. A room in another factory belonging to the same firm was shortly to be devoted to dipping and it was decided to give this new bench a fair trial there.

Everything having been done by extensive motion study to reduce the labour of the workers, the experimenter turned his attention to the more intricate problem of intensive motion study.



No. I.—Usual Method of Dipping Sweets.



No. II —New Method of Dipping Sweets. *Note curved movement.*

It was found that the path usually followed by the workers' hand when dipping was such as the following diagram may illustrate.

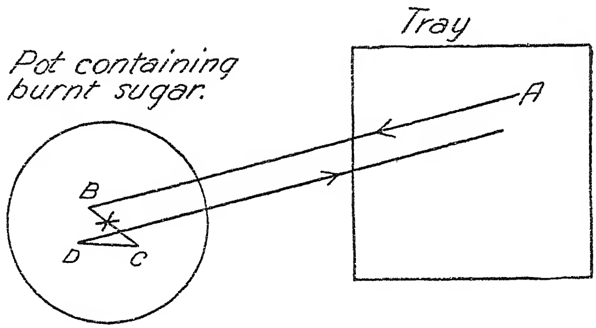


FIG 1 —OLD METHOD OF SWEET DIPPING.

It must not be supposed that this diagram represents the exact line followed. No human movement would ever be so exact, besides which no account has been taken of certain small movements made necessary in order that the sweet may be of the proper size. The exact path followed by this movement may be seen in No. I photograph and the lettering in the diagram corresponds to the lettering in the photograph.

The stroke A B, is not given in photograph No. I. Its commencement can be detected at about the same place as is afterwards covered by C. In photograph No. II, its commencement can be more easily seen.

The right hand holding the fork goes from A to B and takes up a portion of the thick liquid and pulls it over the centre at X. When the hand reaches "C" it goes forward towards the left side of the bowl with the end of the fork under the centre. The centre is then picked up at "D" and deposited in the tray This would appear to be the best way of doing the operation, because the hand is always travelling in approximately straight lines. The defect of this method is that the hand stops at B and goes in the opposite direction and also at C and goes again in the opposite direction. The necessity of having to stop the arm twice and change the direction causes unnecessary strain to the arm muscles.

After some personal experience on the part of the experimenter in the process of dipping, he decided to recommend a method of doing the work in which the hand moved in

curves instead of in straight lines. The new method may be diagrammatically represented as follows :—

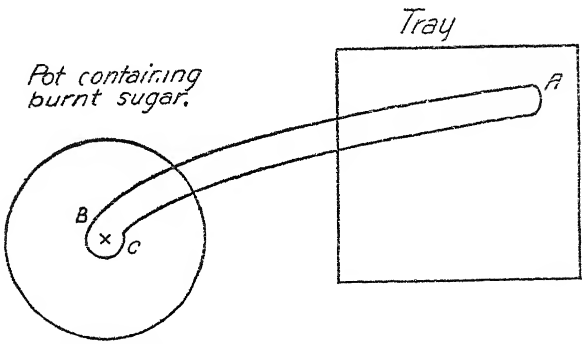


FIG 2—NEW METHOD OF SWEET DIPPING

The hand after depositing the finished sweet leaves " A " and reaches " B " on the surface of the boiled sugar in the middle of an inward and downward curve with the hand in its strongest position for doing work The momentum gained by the movement A—B is thus utilised for the most tiring part of the work, instead of being entirely wasted by checking the movement in order to change its direction as in the old method. This curve sweeps the sugar over the centre and going under it in the second part of the curve comes up again at C. The sweet is then deposited on the tray. A circle in the same direction is made there also in order to finally finish off the sweet. In this method the hand is never brought to a sudden standstill but continues in an even circular movement, all change of direction being effected by curves and not by stopping the hand. It moreover has the advantage that the fork strikes the boiled sugar (the part of the process offering the greatest resistance to the hand) with a downward and inward stroke and with the full momentum gained by travelling from A to B. In the old system this part of the process was done by a short backward movement just after the hand had stopped and changed direction. The diagram of this motion should be compared with Photograph No. II, where the curve B—C can be clearly seen. The diagrams represent the movement as seen by the worker. The photographs represent the movement as done by the worker and seen by the observer standing in front of the worker.

The best workers in the department were then examined to see if any of them worked in the method suggested. It was found that the three whose output was greatest did, at times, adopt a method similar to, though not quite identical with, the one suggested. It was found impossible to get the workers who had been accustomed for years to another method of work to adopt the new method. It was therefore decided to endeavour

to get the younger members of the department to adopt it, and for this purpose a class was instituted. The result after a short training was an average increase of 27·1 per cent., but it was felt that even this increase did not fully represent the benefits to be gained by the new method. The instructress who had charge of this class was not a very proficient teacher, and the young girls, seeing older girls around them working in a different way and, of course, turning out more than the younger girls were able to, showed a tendency to drop the method they had been taught and adopt the one they found going on all around them, and, apparently, producing better results.

For this reason it was decided to concentrate attention on the new room that was to be started. A more proficient instructress was found, the new-sized table and trays were employed, and arrangements were made whereby the workers were enabled either to sit or stand while at work. It must also be added that this new room was lighter and better ventilated than the old one had been. After three months' work in the new room the workers were, on an average, producing 88 per cent. more than workers of the same standing who were working on the old method in the original room. This increase meant that girls of 14 and 15 were earning a sum equivalent to that earned by girls of 18 in the old room, showing that the correspondence between age and output in the old room was not entirely due to the superior strength of the elder girls, but that difficulty in forming an easy motor habit at least had something to do with it. The new system of movements was far more natural than the old one and, therefore, presumably easier to learn.

§3.—An Experiment in Bottling Sweets.

The process of putting sweets into small glass jars is one that entails a considerable number of operations. The sweets have first to be tightly pushed in the jars to prevent them rattling, a pad is then put on top of them. The lids have to be waxed before being affixed, and the affixing of the screw lids requires a certain amount of effort on the part of the worker. Three different types of labels have then to be stuck on the jars and, finally, the jar is cleaned and removed to the packing department. Originally, all these processes were done by the same worker, which entailed a good deal of wasted effort. A number of jars were dealt out to her and she had to find room for all of them near her on the bench throughout the whole operation. The result was that a considerable amount of confusion was at times, caused, and the worker was required to stretch unduly far to reach the jars on the outside of the group.

The experimenter also noticed that the workers tended to do nearly all the work with the same hand. They would pick up the jar from the right hand side with the right hand, work on it with both hands and put it down on the left hand side with the right hand. Or they might pick up with the left hand from

the right side and put down on the left side with the left hand, and every other possible combination of right and left hand was to be found in the room. It was thought that if the work could be more equitably apportioned between the two hands, and some system devised where both hands worked simultaneously instead of one working while the other rested, that a more satisfactory way of doing the work might be found.

A distinction must be made between ambidexterity and bimanufiability. By the former is meant the power of being able to do an operation equally well with either hand, by the latter, the power of doing one thing with the one hand while doing something else with the other. People who shave themselves with either hand are ambidexterous, people who can put down an object with one hand while taking up another object with the other are bimanuficient. Ambidexterity is not brought into play in the process of bottling here described, but bimanufiability is.

A system of movements was devised which depended on this latter quality being utilised and elaborate diagrams were made of the movements for each process, but it was found impossible to get the workers to understand what was required of them.

A method of doing the work was therefore devised by which the whole process instead of being done by one worker was done by a team of workers, each worker doing one particular operation. To facilitate matters a moving belt was placed on the bench along which the jars travelled and were thrown off close to the worker who was to do the next process. It was felt important that no worker should be required to do one process for too long at a time, but this was easily overcome.

The screwing on of the lids was the most tiring operation in the task, and so it was arranged that no girl should screw for more than half an hour. The relief given to the "screwer on" provided an opportunity for a change for each worker every half hour, which was better than any arbitrary arrangement it might have been necessary to make if all the processes had been of equal difficulty.

Careful timings of all the operations had been made so as to discover the time relation in which one process stood to the others in the series, and the number of workers were apportioned accordingly. Even so, slight difficulty arose in the proper proportion of workers to allow for each process, but these difficulties were overcome by practical experiments. There was some difficulty at first in devising a proper system of payment that should be fair to those doing the new work. The original method was that each worker was paid by piece rate on her individual weekly output, but to continue this method when the work was done by a team was obviously impossible. Various schemes were tried, based on the principle that the same piece rate per dozen jars should be paid as when the workers were paid on individual piece rate, but the difficulty was to divide this

equitably among the various workers. Finally, the workers themselves suggested a method of payment which they thought fair, and their suggestion was immediately adopted by the management.

The new system has been working for some time now with the result that the workers' average output and earnings are about 50 per cent. greater then when the previous system was in vogue. Further than that, so much floor space is saved by the new method that the room will accommodate 90 per cent. more workers than was previously possible.

The interesting feature of this experiment is that the method of work adopted provides that the jar to be worked upon shall always arrive at the right hand side to be picked up by the right hand, and that the jar that is finished is always put down on the left hand side, and this process being facilitated by the belt. The result is that without any instruction the workers have learnt to pick up one jar while they put down another, in fact have learnt in this respect to become bimanuficient.

§4. An Experiment in Covering Chocolates.

The process of covering chocolates by hand is done by women workers, who sit at a large round table on which the chocolate is kept at the temperature that will allow it to be most efficiently worked.

The worker drops the centre in the chocolate with her left hand and covers it with a fork held in the right hand.

The work is similar to and at the same time different from the work previously described in dipping sugar goods. It is similar in the sense that a centre has in both cases to be covered and so the movements of the hand should be almost the same in both cases. It is different, because in the one case the centre is covered with boiled sugar, and in the other with chocolate.

The sugar adheres to the centre without much difficulty; in the case of chocolate covering, considerable skill is required to get the chocolate to adhere in the right quantity and thickness. This is greatly affected by the temperature of the chocolate and work is spoilt if the chocolate is either too cool or too warm.

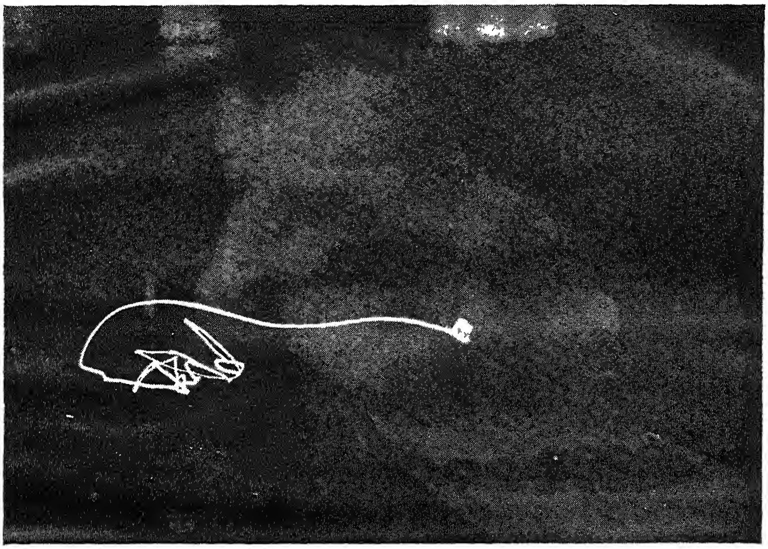
In examining the workers in the chocolate dipping department it was found that almost every worker had a different method of work. Some were able to perform the operation with a comparatively small number of movements and others employed a great number of movements. The workers differed in the size of the movements they found it necessary to employ, some making very extended movements though few in number, and others making the same number of movements though less extended in nature. This can be illustrated by reference to the photographs No. III is the best worker in the department. She had had fourteen years' experience and her output was generally about 100 per cent. more than the average good worker

of her standing. She worked with great rapidity and she also possessed great power of motor control. No. IV is a worker with a great number of years' experience. It will be seen that her movements are more in number than those of No. III and also more extended. No. V shows a worker of many years' experience making a great number of movements but of a not very extended nature.

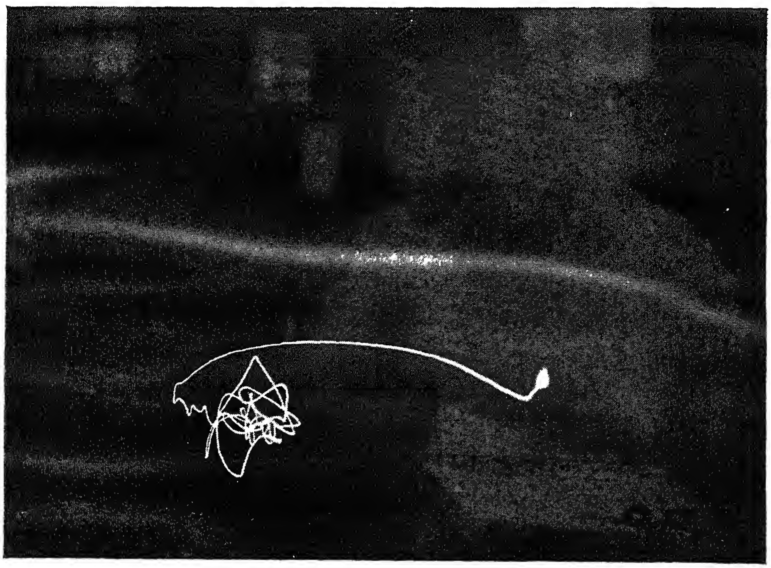
The investigator hoped he would be able to reduce the number of movements employed in chocolate dipping by getting the workers to adopt the rhythmic curved movement that was employed in sugar dipping, but he realised that no definite rule could be laid down as to the exact number of movements necessary on account of the technical difficulties connected with the thickness and temperature of the chocolate. He therefore decided to suggest a method and to leave it to each worker to decide how many movements she would take to do the work. Photograph No. VI shows the investigator covering chocolates with three movements, "a," covering the centre, "b" and "c," draining the chocolate off. No. VII shows the worker who was selected to instruct in the new method doing the work in four movements, "a" and "b," covering centre twice, "c" and "d," draining twice. No. VIII shows a beginner instructed in the new method, doing her work after only six months' experience. It will be noticed that she drains the sweet in the same place as she dips it, a method adopted by some workers. No. IX is another worker with the same amount of experience, but with a different type of movement, employing the new method. Her rhythm is of the same type as that of No. V and might be compared with it. The rhythm employed by No. VIII is comparable with that of No. IV. It will be seen, however, that Nos. VIII and IX although only young girls of six months' experience are doing fewer movements than No. IV or No. V who have both had several years' experience.

The training of the new group of workers took place in a separate room and they were instructed in the circular method of doing the work, *i.e.*, they were told to move as far as possible in curves rather than in straight jerks, and also to endeavour to make as few movements as possible. There was no attempt to limit the number of movements or to enforce a rigid uniformity in the method adopted.

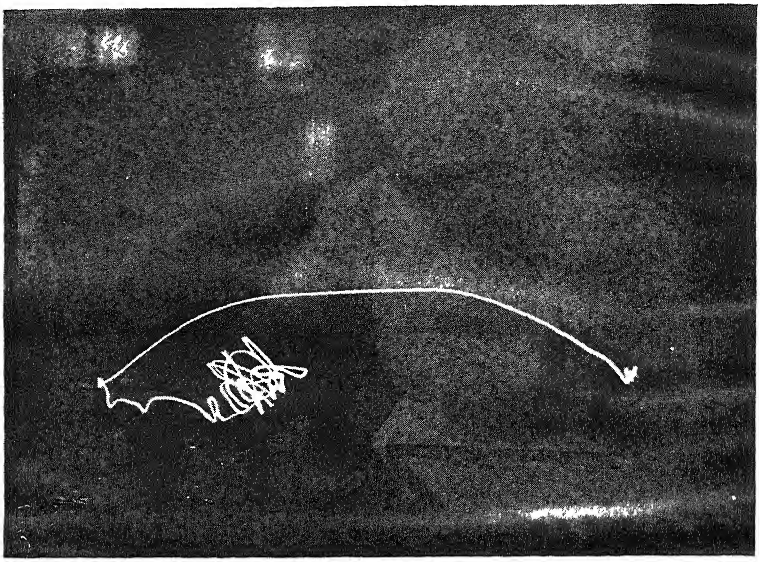
The workers found the new method of working so easy that in a few months their piece rate earnings were equal to the earnings of girls of several years' standing. When they had reached that standard they were moved into the room with the other workers. Many of the older workers became most interested in the new method and began to pay attention to the number of movements they employed. The forewoman was of opinion that the new method had had a most beneficial effect upon the whole department, and she was sure that the dippers as a whole were employing fewer movements.



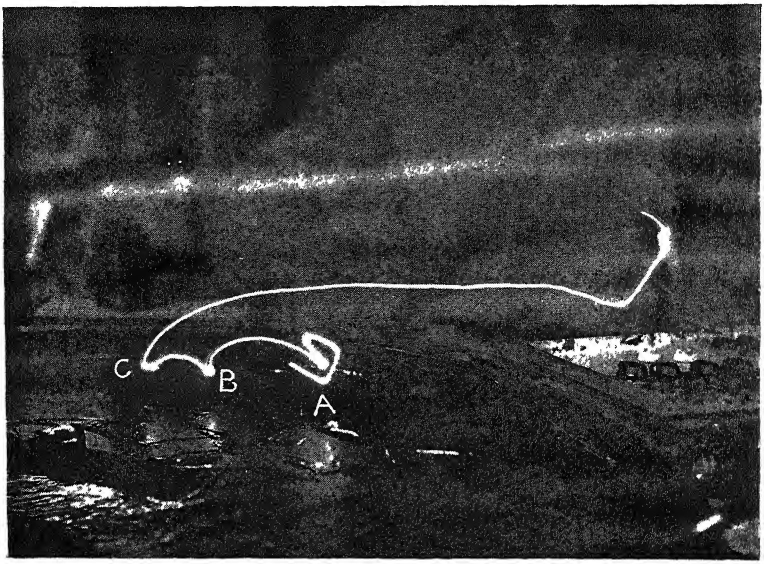
No III —The Best Worker in the Chocolate Covering Department.



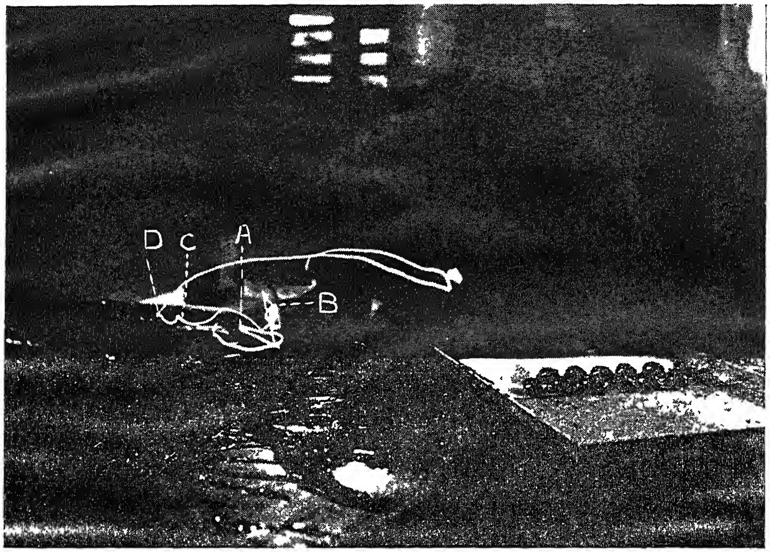
No. IV —A Worker of Many Years' Expfrience making many Unnecessary Movements.



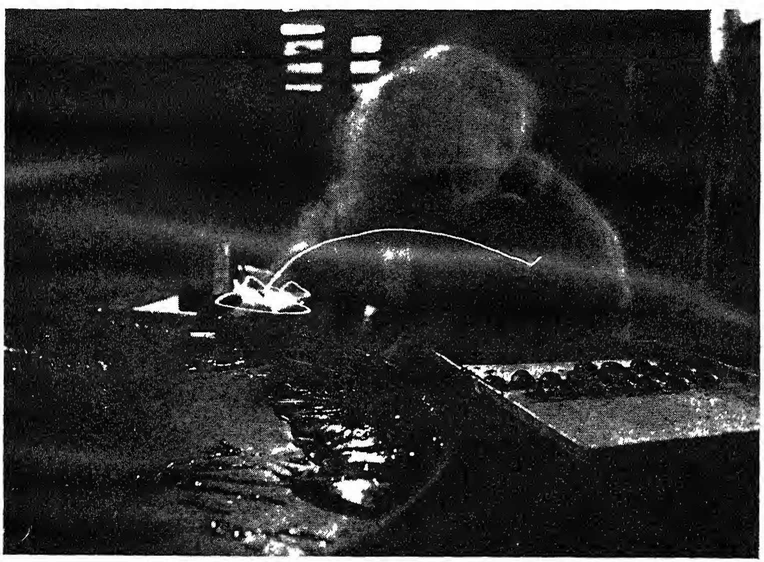
No V.—An Experienced Worker with different Type of Movement



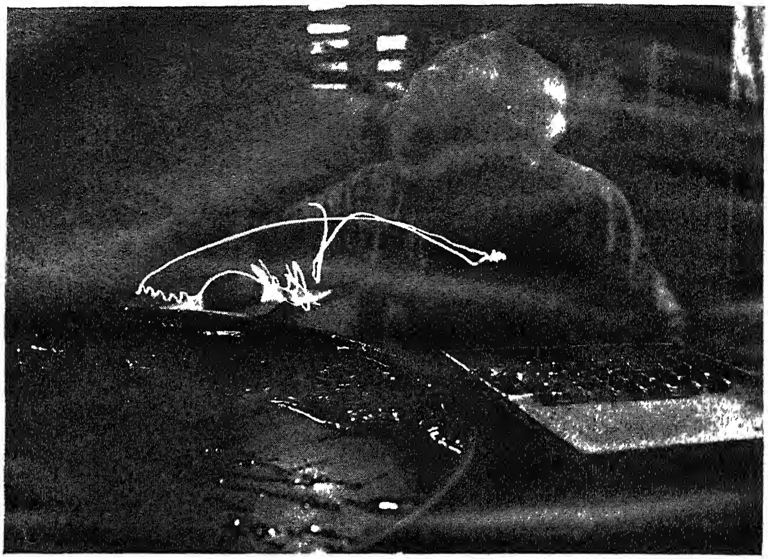
No. VI.—The Investigator Covering Chocolates.



No VII —The Instructress in the New Method of Covering Chocolates



No. VIII —One of the Pupils after Six Months' Experience



No. IX.—Another Pupil with Same Amount of Experience.

The new movements seemed so easy that there was a reluctance in some girls to adopting them, as they felt that by doing so they would not be working as hard as they ought to. One worker said that she liked the new method but had decided not to adopt it because if she did she might be accused by those in charge of the department of not working hard enough. She was, however, persuaded to adopt the new method and made very favourable progress.

This example of motion study is an instance of how a principle can be laid down on which work should be done, without in the least interfering with the natural rhythm of the worker. The process of covering chocolate is very intricate and cannot be hurried, since a certain amount of time must be allowed for the chocolate to cool sufficiently for it to adhere to the centre. These minute fractions of time can best be measured by each worker beating to some rhythm that she finds natural. All that can be done to improve the method by motion study is to suggest an easy method of moving the hands and to get each worker to try and do the work in as few movements as possible.

It was not possible to compare the output of these workers with others of the same standing because there were no other workers in the same position. All that could be done was to see how long it took to become proficient in the method as compared with the old method. The time required was found to be much shorter than was the case with the original methods.

§5.—An Experiment in Chocolate Packing.

There are various ways of arranging for the supply of chocolates to be packed, but the most usual is either to arrange the chocolates on trays one above the other immediately in front of the worker, or to have them in boxes spread out before the worker in two horizontal planes. The system of packing in vogue in the particular factory in which the experiment was carried out was of the latter type.

The worker stood at a bench at the back of which were racks arranged to hold. twelve boxes of chocolates in horizontal and parallel lines. Each box contained a different sort of chocolate and the chocolates were arranged by the packer in the box she was packing according to a prescribed pattern. The patterns were arranged with the object of looking artistic and thus catching the purchaser's eye. The result of this was that any particular type of chocolate might occur at irregular intervals in the pattern. This necessitated the packer as she worked along each row of chocolates in the pattern taking chocolates from boxes irregularly placed in front of her. The pattern might for instance necessitate that her movements were in the following order :—

One chocolate from boxes 1, 2, 3, 4.
Four chocolates from box 6.
One chocolate each from boxes 3, 4, 5, 6
Four chocolates from box 1,

n.

Sometimes there are only six kinds of chocolates to be packed into the same box, but in some cases there are twelve, and it can easily be imagined how very complicated the system of movements can become if the pattern is designed with no regard to easy packing.

It was noticed that each time a fresh chocolate was taken from the box the worker looked up to make quite sure that her hand went to the right box. It was thought that if a more systematic method of arranging the boxes could be devised so that the hand travelled in a smooth rhythmic way from beginning to end, the worker would be saved much fatigue. In order to attain this it was necessary that the hand should travel in the order 1, 2, 3, 4, etc., and when the last box had been reached should be ready to start again in box No. 1.

This could be arranged by duplicating the box containing a particular type of chocolate each time it was repeated in the pattern. To do this is impossible because it would necessitate too many boxes of chocolates, some of which would be out of the easy reach of the worker. In practice it is not found possible to work with more than twelve boxes at one time.

The only way to ensure easy rhythmic movements on the part of the worker was to design patterns which made it possible and at the same time were attractive to the eye. This was done, with the result that the new patterns necessitated chocolates being taken from the boxes in something like the following order :--

Bottom layer.	Top layer
1, 2, 3, 4, 5, 5, 5, 5. 6, 7, 8, 9. 10, 10, 10, 10	11, 12, 1, 2. 3, 3, 3, 3. 4, 5, 6, 7. 8, 8, 8, 8, etc

This is only an example and an infinite number of patterns are possible which still allow the worker to move in an ordered way. The worker's hand still has to move from the centre of the bench where the box she is packing is situated to the circumference where the boxes she is taking chocolates from are situated ; but instead of having to make a separate decision each time a chocolate is required as to which box to find it in, her movements can now be made in a semi-automatic fashion, simple movement associations being formed which directly correspond with the visual association of the required pattern.

A new bench was designed which enabled the worker to sit while at work, and the boxes from which she was packing were arranged in a semi-circle instead of in a straight line in front of her. The sides of the semi-circle worked on hinges and could thus be easily adjusted by the worker to the position she found it most comfortable to work in. The new method of packing resulted in an increased output of 38 per cent.

During the progress of the experiment an interesting incident occurred which is worth recording. The investigator was talking to a colleague who had charge of the experiment at some distance from the worker, and could only see her face above the bench. At regular intervals he noticed that a frown came on it and he felt convinced that one of the boxes was out of place so that the regular order of movement was broken once in each cycle. On going up to the bench he found that this was so. The boxes were not quite accurately adjusted to the pattern, so that at a particular point the system broke down and necessitated a mental decision on the part of the worker. This little incident illustrates how much saving in mental fatigue can be effected by adjusting the work in such a way as to allow it to become semi-automatic.

In all these experiments no stimulus of any kind was given to the workers to increase their output. The principle in each case was to devise what was believed to be an easier way of doing the work and then to leave the matter in the workers' hands.

PART III.—BIBLIOGRAPHY.

§ 1.—BOOKS.

AMAR, JULES. *The Human Motor.* London, Routledge, 1920.

Book VI.—Deals with the physiological measurement of fatigue caused in industrial processes. Experiments were made on a filer at work. An apparatus (carefully described) was attached to the file for measuring the amount of pressure exerted, and another apparatus was attached to the mouth and nostrils in order to measure the amount of CO_2 given off After various experiments the right position of the feet and the right number of strokes per minute were discovered. An apprentice was then instructed in the new method, which included rest pauses, and he very soon became an expert workman. Besides this definite experiment in motion study the book contains information as to the various ways of measuring effort, and also deals very fully with such subjects as rhythm and positions of the body in various occupations.

——. *The Physiology of Industrial Organisation and the Re-employment of the Disabled.* London, The Library Press, 1918.

This book, like *The Human Motor*, contains a great deal of information concerning physiological measures of fatigue. The improvement effected in filing mentioned in *The Human Motor* is also described here The best methods of walking, and the most economical pace under various conditions are discussed. The subject of shovelling is treated in a similar way and a slightly different conclusion arrived at from that of Taylor.

ATKINSON, H. *A Rational Wage System.* London, Bell, 1917.

A very clearly written book dealing with the problem of fair remuneration based on time study. Part I is devoted to general principles and Part II deals with the detailed application of these principles The author derives his experience from two English engineering shops. The work is of a high standard, and the question of the effect of the introduction of time study on the relation between employer and employee is dealt with from an independent point of view.

DIEMER, H. *Factory Organization and Administration.* London, Hill Publishing Co., 1914.

Chapter XXI and XXV, *Rate Fixing and Time Studies*, advocates that the fixing of rates should be based on scientific time study and suggests certain methods. There is a good description of Taylor's work, a division being made between its analytic and constructive aspects.

FARNHAM, D. T. *Scientific Industrial Efficiency.* Chicago, Brick & Clay Record Co., 1917.

A book by a typical efficiency engineer. He pays a good deal of attention to the bonus system of payment of which he is greatly in favour.

GANTT, H. L. *Industrial Leadership.* New Haven, Yale University Press, 1916.

Puts importance on the necessity of properly training operatives.

——. *Works, Wages and Profits.* New York, Engineering Magazine Co., 1919.

The subject of time study is touched upon in various places in the book, but there is no section definitely devoted to it.

GILBRETH, F. B. *Bricklaying System.* Chicago, M C. Clark Publishing Co., 1909.

A complete manual of all the motions required for bricklaying. It is the most remarkable book of its kind, but can hardly be appreciated except by those who are themselves experts in the art of bricklaying.

——. *Primer of Scientific Management.* London, Constable, 1912.

Defines the terms used in Scientific Management and among them time and motion study.

——. *Fatigue Study.* London, Routledge, 1916.

The book pays special attention to the proper seating of workers and gives illustrations of different types of chairs suitable for special occupations. Micro motion study is discussed and the cyclegraph and chronocyclegraph are described.

An account is given of the adjustments Gilbreth made for the proper assembling of braiding machines. The new method of work resulted in 66 machines being assembled, per man, per day, whereas previously 18 machines per day was considered a good day's work

There are many excellent illustrations in the book of labour-saving devices, patent chairs, and chronocyclegraphs.

——. *Motion Study.* London, Constable, 1911.

A considerable part of the book is devoted to Gilbreth's doctrines of variables, *i.e.*, all the varying factors affecting the work or the worker. The general principles of motion study are very clearly dealt with, and many examples are given of improvements effected by it. These examples are all taken from bricklaying and will be found in Gilbreth's book on *Bricklaying*.

——. *Motion Study for the Handicapped.* London, Routledge, 1920.

A series of papers read by Gilbreth dealing with various appliances for overcoming the disabilities of the crippled. There are interesting illustrations of the way in which many of the ordinary occupations can be made possible for the crippled.

GILBRETH, F. B., and GILBRETH, L. M. *Applied Motion Study* New York, Sturges & Walton, 1917.

The book outlines the general principles of motion study and indicates its place in scientific management. Certain results obtained by motion study are given in Chapter III. The motions used in laying a brick were reduced from 18 to 5, with an increase in output of from 120 to 350 an hour; in folding cotton cloth, 20 to 30 motions were reduced to 10 or 12, with a result that 400 doz. pieces of cloth were folded in the same time that it had previously taken to fold 150 doz. The methods of a girl putting paper on boxes were altered, with the result that she did 24 in 20 seconds instead of in 40 seconds as had previously been the case.

There is a very full description of all the apparatus used by Gilbreth, together with illustrations, among which are to be found photographs of the wire models he uses for teaching a new motion.

GILBRETH, L. M. *Psychology of Management.* New York, Sturges & Walton, 1914.

Certain parts of the book are devoted to the principles of motion study, but for the most part it is concerned with scientific management.

HAMP, PIERRE. *La France Pays Ouvrier* Paris, Nouvelle Revue Française, 1916.

Deals briefly with the question of rhythm.

HAUER, D. J *Modern Management Applied to Construction.* New York, McGraw-Hill, 1918.

Chapter VI.—The author found it possible to "about double" the daily output of a group of men addressing envelopes by making certain changes in the desks used. He also carried out time studies on the loading of "two hone wheel scrapers on railroad construction," with the result that the output of the scrapers was increased over 20 per cent.

Most of the chapter is devoted to a very careful discussion of shovelling. It is treated from every aspect, *e g.*, short-handled *v* long-handled shovels, the shape and size of shovels, height of the throw the best motions for efficient shovelling (with diagrams), dimension. of shovels, etc.

HOME OFFICE REPORT (Welfare Pamphlet No. 6). *Seats for Workers in Factories and Workshops.*

Contains interesting photographs and diagrams of seats suitable for different types of industrial occupations.

An account of an experiment in rest pauses in an English factory which resulted in considerable increase of output is also given.

HOXIE, R. F. *Scientific Management and Labour.* New York, Appleton, 1916.

Is a report by the United States Commission on Industrial relations. It goes into the whole question most carefully. The position taken with regard to time study is similar to the one in this report.

HUNTINGDON, E. *Civilisation and Climate.*

Does not actually deal with motion study but has a considerable amount of data dealing with the effect of climate, seasons and temperature on work which certainly bears on the subject.

KNOEPPEL, C. E. *Installing Efficiency Methods.* New York, Engineering Magazine Co., 1917.

Chapter XI.—Gives instructions how to carry out time studies and also examples of time sheets used. An example of time study to indicate fatigue is given in the case of a man grinding castings. At the beginning of the work he took 739 mins. per piece, half way through ·907 mins, and at the end 1·07 mins Chapter XVI deals with standardisation.

LAHY, J. M. *Le Système Taylor et la Physiologie du Travail Professionnel.* Paris, Gauthier-Villors & Cie., 1921.

A very valuable critical appreciation of Taylor's system. Chapter III deals with motion study The general conclusions to which Lahy comes are that it is possible to determine scientifically the best methods of using human energy in industry by a study of the physiological and psychological processes involved, but that all such experiments to be truly applicable should be carried out in the factory under normal conditions and not confined to the laboratory.

LEFEVRE, THEOTISTE. *Guide Pratique des Compositeurs d'Imprimerie.* Paris, Froinin Didot, 1855.

A description of the processes involved in printing. Careful instructions (with illustrations) are given concerning the correct movements that a compositor should make and the exact position of his hands.

LEFFINGWELL, W. H. *Scientific Office Management.* New York, A. W. Shaw, 1917.

In The Chicago Ferrotype Company, motion studies resulted in reducing the motions necessary for opening letters from thirteen to six which resulted in 200 letters being opened in an hour when previously 100 had been opened. Further experiments and more efficient desks resulted in 300 letters an hour being opened.

One clerk's output was doubled by the re-arranging his desk.

A mail order house saved 45 per cent. of its labour cost as a result of careful time analysis of its office organisation.

A clerk using a rubber stamp, a pencil and a numbering machine was taught to use them always in the same order. A 25 per cent. saving in time was effected.

An example of the Taylor system in practice Everything is done to save time and speed things up. The book lacks both contents and index and no details of how the improvements were effected are given.

McKILLOP, M. *Efficiency Methods.* London, Routledge, 1920.

Chapter IX is devoted to time and motion study. Instructions are given as to the way to take a time study and many of Gilbreth's photographs are reproduced. Reference is made to certain of Taylor's and Gilbreth's results but no new experiments are given.

MAREY, E. J. *Movement.* London, Heinemann, 1895.

This book is a very complete study of movement. It is full of the most ingenious methods of measuring the movement of men, animals and liquids, and is well worth careful study by all who are interested in the study of movement.

MOSSO, H. *Fatigue.* Paris, F. Alcan, 1894. (Translated by M. & W. B. Drummond, The Science Series, New York, Putnam, 1915.)

A most important contribution to the study of fatigue. Motion study is not actually dealt with but the study of it is so closely allied to that of fatigue that this book should certainly be read by those interested in motion study

MÜNSTERBERG, H. *Psychology General and Applied.* London, Appleton, 1914.

Chapter XXXI —Treats of economic psychology and discusses the proper method of training beginners in industry. The subject of motion study is mentioned, and the lines of research in order that it may be put on a really scientific basis are indicated.

——. *Grundzuge der Psychotechnik.* Leipzig, 1914.

Chapter VI.—Treats of industrial psychology and pays considerable attention to the problem of adjusting work and the machinery to the worker in such a way as to cause the least possible amount of fatigue. The principles on which scientific motion study should be based are clearly brought out, but no new experiments are given.

——. *Psychology and Industrial Efficiency.* London, Constable, 1913.

Contains a valuable discussion on scientific management and has a chapter devoted to the subject of economy of movement. Some of Gilbreth's and Taylor's experiments are discussed, but no new matter bearing directly on the subject of time and motion is given. The book is, however, full of useful suggestions of the way psychology can be employed in industry, and a great many of these suggestions bear very directly on the subject of time and motion study. The principles Munsterberg lays down in other books do not differ from those given here, but they are more fully worked out. Such subjects as rhythm, attention, stimulation by colour and sound are among those which Münsterberg deals with in this book.

——. *Business Psychology.* Chicago, La Salle Extension University, 1915.

This book is mainly devoted to showing in what way the various psychological processes are brought into play in business Motion study is briefly dealt with, but nothing new is said about it.

MUSCIO, B. (Edited by). *Lectures on Industrial Administration.* London, Pitman & Sons, 1920.

A series of lectures given at Cambridge by various lecturers dealing with different aspects of the human factor in industry A lecture by A R Stebbing treats of the application of Taylor's principles in British industry.

MUSCIO, B. *Lectures on Industrial Psychology.* London, Routledge, 1920.

Lecture IV treats of the best method of work and discusses the problem of time and motion study, making suggestions as to its proper use.

MYERS, C. S. *Mind and Work.* London, University of London Press, 1920.

Chapter I is devoted to movement study. Instances are given of the results effected by the introduction of a properly studied system of movements and the need for further research is pointed out.

PARKHURST, F. A. *Applied Methods of Scientific Management.* New York, Wiley, 1917.

Briefly describes the principles and application of time study, but the main portion of the book is concerned with management and general schemes of speeding up industry.

PUBLIC HEALTH BULLETIN, No 106, U.S.A. *Comparison of an Eight Hour Plant and a Ten Hour Plant.* Public Health Service, Government Printing Office, Washington.

Chapter IX deals with rhythm in industry. It points out that the output curves of rhythmic industrial processes have practically no tendency to fall off at the close of the working period, as is the case with most other output curves The time taken to perform such processes varies very little throughout the day. The data dealt with in the report are not sufficient to decide whether this lack in variation of output is due to lessened fatigue or to the fact that rhythm obscures the effect of fatigue. A further report dealing primarily with rhythm is promised which should be of considerable interest.

SPOONER, H. J. *Industrial Fatigue in its Relation to Maximum Output.* London, Co-partnership Publishing Co., 1917.

Devotes a certain amount of attention to the consideration of motion study.

——. *Wealth from Waste.* London, Routledge, 1918.

Treats of time and motion study in various parts throughout the book, but there is no section specially devoted to it.

TAYLOR, F. W. *A Piece Rate System and Notes on Belting.* New York, Harper, 1911.

Contains an appreciation of Taylor by F. B Copley. A good idea can be gathered from this book of Taylor's methods of remuneration and also the work he did on the proper speed of machines.

——. *Shop Management.* New York, Harper, 1911.

An account is given of the work done by Taylor on men loading pig iron.

Page 81 ff. A standard steel forging which it was customary to turn out at the rate of five per day was time studied and the differential piece rate was introduced. It resulted in 10 pieces per day being turned out instead of five, and the men's earnings were increased from $2·50 to $3·50 per day.

Page 87 ff. An account is given of the improvements effected by Taylor in the work of the girls examining bicycle balls. No mention is made of scientific selection.

Page 179 ff. An account is given of the elaborate experiments Taylor instituted to determine the proper cutting tools to use in an engineering work. His final results were worked out mathematically and a system of formulae invented, which it is claimed enabled the workman by the use of slide rules to determine exactly what tool and speed to use for any particular metal.

Page 181 ff. Cleaning out boilers was time studied and the job paid by piece rate instead of day rate. It resulted in a reduction in the cost of cleaning out a set of boilers from $62 to $11.

——. *The Principles of Scientific Management.* New York, Harper, 1914.

Chapter II contains an account of Taylor's work on handling pig iron The ordinary amount handled was 12½ tons per day and the wages of the men were $1·15 per day. After the process had been time studied 47 tons were carried per day and the wages of the men were increased to $1 85 per day. This was accomplished by the systematic introduction of rest pauses. The workman "worked when he was told to work and rested when he was told to rest." The men were specially selected on account of their superior strength.

Page 53 ff. deals with the experiments carried out under Taylor's guidance to determine how much work a man can profitably do in a day A law was finally formulated showing that the work a man ought to do varied with the nature of the work In carrying pig iron (each pig weighing 92 lbs) a first-class workman can only be under load 43 per cent. of the day. When the pig weighs only 46 lbs. the workman can be under load 58 per cent of the day. No details of how these results were arrived at are given except that Mr. Barth worked them out graphically

On page 65 ff. an account is given of the experiments Taylor made in determining the right load to be taken at one time in a shovel, which he found to be 21 lbs. This experiment was carried out by getting two or three first-class shovellers to work at their top speed by paying them extra wages and then varying the load of the shovel and noting the results. Observations were also made to determine the best kind of bottom on which to shovel and "the time required to swing the shovel backward" for various distances and height, but the results of these experiments are not given. The new method, however, resulted in each man shovelling an average of 59 tons per day, whereas on the old system he had only been able to shovel 16 tons

An account is given of Gilbreth's work on bricklaying, page 77 ff

An account is given of Taylor's work on the testing of bicycle balls, page 66 ff. By shortening the hours, introducing rest pauses, increasing the pay and scientific selection of the worker, "thirty-five girls did the work formerly done by one hundred and twenty," and "the accuracy of the work at the higher speed was two-thirds greater than at the former slow speed Taylor says that "the scientific selection of the workers" was "the one element which did more than all of the others" to bring about this remarkable change

By studying the proper speeds for cutting tools, the way they should be ground, dressed, etc., and then devising "four quite elaborate slide-rules" by which it could be determined what was the best tool and speed to use for cutting any particular article in the lathe, the output per man of a machine was more than doubled. The average increase in daily earning was 33 per cent., page 98 ff.

THOMPSON, C. B., *The Theory and Practice of Scientific Management.* New York, Houghton Mifflin, 1917.

Discusses the difference between Taylor's system and its development by Gantt and Emerson. The general principles of time and motion study are dealt with, but no new experiments are given.

THOMPSON, C. B. (Edited by). *Scientific Management.* London, Humphrey Milford, 1914. *Elementary Time Study as a Part of the Taylor System of Scientific Management,* page 520.

Explains Taylor's system of time study and gives classified lists of time units for doing certain jobs in engineering shops.

VAN DEVENTER, J. H. *Machine Shop Management.* New York, McGraw-Hill, 1915.

Has a section dealing with time study Instructions, based on the Taylor system, are given.

VIELLEVILLE, A. *Le System Taylor.* Paris, Imprimerie Vielleville, 1914.

Discusses the general principles of Taylor's system with special reference to his method of payment, which he regards as the best method of compensating the workman for the increased effort he is required to put forth.

WHITEFORD, J. F. *Factory Management Wastes.* London, Nisbit & Co., 1919.

In Chapter VII the author briefly discusses the subject of time and motion study and advocates its adoption.

——. *How Scientific Management is Applied.* New York, The System Co., 1911.

Chapter III contains a short account of how the time for a gear cutting operation was reduced from 322·4 hours to 188·1 hours. In another operation the time was reduced from 4·4 hours to 1·5 hours and in another from 2·4 hours to 0·45 of an hour.

The output in a bleaching and dyeing establishment was doubled by a rearrangement in the process of folding.

The following books also deal with the subject:—

GILETTE, H. P., and D. R. T. *Cost Keeping and Management Engineering.* New York, M. C. Clarke & Co., 1916.

LODGE, W. *Rules of Management.* New York, McGraw-Hill, 1913.

SHEPARD, G. H. *Application of Efficiency Principles.* New York, Engineering Magazine Company, 1917.

§2—REFERENCES IN PERIODICALS.

ADAMSON, N. E. (Junr.). (1911). The Taking of Time Study Observations. *Industrial Engineering & Engineering Digest.* New York. **10.** 439.

Gives various ways of taking the times of operations connected with making paint drums. The matter is carefully and accurately dealt with and should be of assistance to those interested in the trade.

——. (1911). Time Study Observations. *Iron Age.* New York. **88.** 1090.

Describes various methods of making time studies with special reference to the making of paint tins.

——. (1912). Production Betterment by Time Studies. *Ibid.* **89.**

Deals with an improved method of making 10 gallon paint drums. The method is given in detail. The direct labour cost per drum was reduced from \$0·466 to \$0·31, which meant a saving of \$3,750 per annum. The operators were paid by the day and no incentive was given to speeding up.

Bennett, G. L. (1914.) Time Fixing. *Municipal Engineers of the City of New York.* **86.** 5.

Cleary, L. J. (1912.) How Six Managers Saved Lost Motions. *Factory.* Chicago. **9.** 408.

In operations on a wood-working machine the helper had been accustomed to pile door linings with grooved edges upwards It was found by time study that the time taken to turn each piece flat on the "feed roll" was practically "one-half" of the time of the total operation Instructions were given for the helper to pile the stocks with flat sides horizontal, with the result that the output of the machines "was doubled"

A mitre sawyer had his stock loaded on a low truck and used a similar truck for placing the finished articles on, thus causing him to bend twice. Proper trucks were supplied which resulted in an output increase of 30 per cent

In a case where machines were more conveniently grouped so as to facilitate routing, a saving of 40 per cent. was effected. The girls in a match factory who were time studied appeared to expend much time in lifting materials. The legs of their stools were sawn down so as to lessen the distance to be reached. The fatigue thus saved "made more contented and more persistent workers."

In an electric welding department materials had to be dipped in a potash bath. They were done one by one. A tray was made that dipped 100 at a time.

Coburn, F. G. (1912.) How to make a Time Study. *Ibid.* **8.** 21.

Gives instructions how to make a time study. Illustrations of specimen time cards are also given.

——. (1916.) Co-operating in Time Study Methods. *100%* Chicago. **6.** 86, 19.

Colwin, F. H. (1913.) The latest Developments in Motion Study. *American Machinist.* New York. **38.** 937.

Describes Gilbreth's cyclegraphic method of photographing the path of movements.

Crosby, E. L. Some Methods of Standardising Unit Times. *Iron and Steel.* Pittsburgh. **50.** 147.

Dench, E. A. (1916.) Industrial Application of Motion Pictures. *Machinery.* New York. **23.** 133.

An article dealing with the various uses of the cinematograph of which motion study is mentioned as one.

Dowd, A. A. (1915.) The Use and Abuse of Time Studies. *Iron Age.* New York. **95.** 300.

Outlines the way in which time studies should be taken.

Ennis, M. D. (1911.) An Experiment in Motion Study. *Industrial Engineering & Engineering Digest.* New York. **9.** 462.

In giving a course of lectures in Scientific Management, Professor Ennis thought it advisable to give a practical demonstration of motion study. The task selected was the arranging in book form of sheets of typed lecture notes. The first result was that the operation took 1,660 seconds. The improved method took 1,322 seconds.

GANTT, H. L. (1910.) Hipped on Motion Study. *Industrial Engineering & Engineering Digest.* New York. **8**. 307.

Relates how Gilbreth reduced the time for putting wrappers on boxes of boot polish from 40 seconds to 20 seconds for 24 boxes. This was done by altering the position of the materials worked with.

GILBRETH, F. B. & L. M. (1915, December 27). Motion Models. *American Association for the Advancement of Science, Transactions of.* Columbus, Ohio.

Explaining how the motion model is made from the chronocyclegraph. It is of great use in teaching a new movement because it is not an exact reproduction of any particular chronograph but the proper motion made up from the best fruits of each worker. Beginners must be taught to move their hands along motion models at standard speed from the first.

GILBRETH, F. B. (1915, December.) Motion Study for the Crippled Soldier. *American Society of Mechanical Engineers, Journal of.* 670.

Treats of the various methods of helping cripples by means of motion study Photographs are given and also a chart, which enables one to mark exactly what each limb is doing at any one moment.

GILBRETH, F. B. & L. M. (1916, June 3.) Chronocyclegraph Motion Device for Measuring Achievement. *Second Pan-American Congress at Washington, Transactions of.*

In order permanently to eliminate unnecessary motions standard motions must be set up, and these can only be decided upon after careful measurement such as is provided by the chronocyclegraph

GILBRETH, F. B. (1916.) Motion Study for the Crippled Soldier. *Iron and Coal Trades Review.* London. **92**. 158.

An abstract of a paper read by Gilbreth before the American Society of Mechanical Engineers It deals with the general problem of motion study in connection with the crippled A description is given of Gilbreth's apparatus for determining motions.

GILBRETH, F. B. & L. M. (1916.) L'étude des Mouvements par les Méthods Chronocyclegraphique. *Revue Générale des Sciences.* Paris. **26**. 173.

A slightly abridged translation of a paper read before the Second Pan-American Congress at Washington, January 3, 1916. Gives a description of Gilbreth's use of the chronocyclegraph

GILBRETH, F. B. (1912.) Motion Study in the Household. *Scientific American Supplement.* **106**. 328.

Advises the adoption of motion study in the household.

GILBRETH, F. B. (1916.) Effect of Motion Study on the Workers. *American Academy of Political and Social Science.* Philadelphia. **65**. 272.

——. (1915.) Motion Study as an Increase of Natural Wealth. *American Academy of Political and Social Science.* Philadelphia. **59**. 96.

——. (1912.) March. The Place of Motion Study in Scientific Management. *Applied Science.* Toronto Old Series, **24**; New Series, **5**. 177-187.

Gives brief outline of Gilbreth's system of scientific management and shows the place motion study has in it.

GILBRETH, F. B. (1910.) The Economic Value of Motion Study in Standardising the Trades. *Industrial Engineering & Engineering Digest.* New York. **8.** 1 and 102.

An article dealing with the principles of motion study with special reference to bricklaying.

GILBRETH, F. B. & L. M. (1916.) Motion Models and the Age of Measurement. *Dodge Idea.* Mishowaka, Ind. **32.** 662.

——. (1916.) Chronocyclegraph Motion Devices for Measuring Achievement. *Efficiency Society Journal.* New York. **5.** 137.

HATHWAY, H. H. (1912.) Elementary Time Study as a Part of the Taylor System of Scientific Management. *Industrial Engineering & Engineering Digest.* New York. **11.** 85.

Time study was carried out on an operation consisting "of putting a roll of cloth into a machine which, when properly set, automatically cut it up into pieces of the required size." Various alterations were made as the result of time study, such as arranging more convenient racks, providing special tools, making tools as far as possible unnecessary by substituting hand-worked nuts, having the pieces of cloth supplied in one length instead of in several as before. As a result, the operator "turned out twice as much work under the improved conditions as formerly"

Time study on the operation of "winding magnet coils, for small electrical apparatus," revealed the fact that "one-third of the operator's time was found to be wasted through no fault of the operator." Twenty-one per cent. of waste time was due to defective material and the rest to defective apparatus Specimen instruction cards are given and the general method of taking timings is described.

HOLLAND, W. H. (1916.) Fairness of Time Study in Settling Rates. *100%.* Chicago. **6.** 19.

HUNT, R. J. (1912.) Time Study as a Method of Determining Light Efficiency. *Industrial Engineering & Engineering Digest.* New York. **11.** 454.

Experiments in time study were carried out in a moulding shop "on the various operations required to place a casting in a planer and get it ready for planing" The room was approximately 27 ft. by 56 ft. The lighting conditions consisted of one gas arc lamp and one individual sixteen candle power carbon incandescent lamp over each one of three planers The gas arc was rated at 1,200 candle power. For purposes of demonstration five 150 watt tungsten lamps were introduced into the room at a height of 7 feet above the working plane. The results for an operation were, with drop lamps alone 3·258 minutes, with gas arc and drop lamps 3·234 minutes, with tungsten lamps 3·124 minutes

JACOBSON, F. B. (1911.) A Time Study Piecework System. *American Machinist.* New York. **34.** 631.

Gives instructions how to make time studies in a machine shop.

JOHNSON, N. C. (1915.) Materials *versus* Methods. Testimony of Moving Pictures in the Study of Cement. *Engineering Record.* New York. **72.** 684.

Points out the use of moving pictures in determining the best method of mixing cement. It deals more with mechanical efficiency than with human fatigue

KENNEDY, R. E. & PENDLETON, J. C. (1915.) Elimination of Waste Motion in Bench Moulding. *American Foundrymen's Association, Transactions of.* Cleveland. **23.** 311.

Gives details of the proper arrangement of the bench in a moulding shop and of the movements that should be employed. 1·51 minutes was saved on an operation that originally took 5·34 minutes to perform.

KENT, R. J. (1913.) Motion Study for the Move-Man. *Industrial Engineering & Engineering Digest.* New York. **13.** 99.

Advocates the adoption of movable benches in order to save waste motions in handling things. In one case, it is stated that "the output of a given machine was increased 200 per cent. by this method."

——. (1913.) Motion Study in the Box Shop. *Ibid.* 325.

Describes how the re-arrangement of the benches in a room where box making was going on, together with the adoption of movable benches and other labour-saving devices, resulted in an increase of 50 per cent. in the output

——. (1915.) The Utilization of Time Study Data. *Iron Age.* New York. **95.** 1178.

Outlines method of making time studies and gives specimen times of certain operations connected with the lathe.

——. (1913.) Micro-Motion Study in Industry. *Iron Age.* New York. **91.** 34.

Deals with general principles of scientific management and gives an account of Gilbreth's work in connection with braiding machines.

KNOEPPEL, C. E. (1914.) Determining a Fair Standard. *Efficiency Society Journal.* New York. **3.** 24.

——. (1914.) How to make your Time Studies Accurately. *The Foundry.* New York. **42.** 169.

Same articles as in "Transactions of the American Institute of Metals."

—— (1913.) How to make a Time Study. *American Institute of Metals, Transactions of.* Buffalo. **7.** 55.

Says that F. R. Copley reduced the standard time for moulding saddle pommels from 53 minutes to 24. The actual time taken by expert moulders in the new system varied from 20 minutes to 10 minutes. The cost to the Government was reduced from $1·17 to $0·54 and the earnings of the moulders were increased from $3·28 to $5·74.

Another example given is that of a certain moulding operation in a steel foundry. It originally took 147 hours to do. After it had been time studied it was standardised at 85 hours. The men did the operation in 92 hours with the following results :—

Decrease in time ... ... 32·5 per cent.
Increase in production ... ... 60·1 per cent.

The formula for a fair standard is stated to be approximately "one-half the difference between the best time recorded and the average time of the readings, added to the best times, or deducted from the average time."

In a sweet factory the motions necessary for hand-dipping chocolates were reduced from 10 to 7.

Langley, R. W. (1913.) Notes on Time Studies. *Industrial Engineering & Engineering Digest.* New York. **13.** 385.

Deals with task setting and how to overcome difficulties with the men.

Merrick, D. V. (1915.) Making Instruction Cards for Time Studies. *Iron Age.* New York. **95.** 560.

Gives instructions of how to make a time study Illustrations of time study cards also given.

Merton, H. W. (1912.) Sizing up the Man. *Business.* Detroit. **27.** 41–366.

Miller, C. S. Example of Motion Study. *Scientific American Supplement.* New York. **73.** 3.

Morrison, C. J. (1915.) Task Setting. *Engineering Magazine.* New York. **49.** 894.

"Schedule" is submitted for "task" on account of the unpleasant associations connected with the latter

A large planer operation performed by a machinist was scheduled for 24 hours, but it actually took 36 hours The machinist was shown how he had wasted time The job was then completed in 29 hours. This process continued till the operation was accomplished in 24 hours. This method of teaching was adopted rather than giving minute instructions in the first instance in order to get the machinist to think for himself

It was found that men doing heavy work, such as unloading coal or removing tyres from vulcanizers, could work very quickly for short spells interspersed with rests It was found better to give the rests irregularly No details are given. In dipping fondants in chocolate it was found that those who appeared to work quickest did least work on account of their unnecessary movements. The movements were finally reduced to seven.

Nelson, J. (1916.) The Stop Watch and the Lawn Mower. *Iron Age.* New York. **97.** 1397.

A letter from J. Nelson defending the use of the stop watch in industry.

Nock, A. J. (1913, March.) Efficiency and the High-Brow: Frank Gilbreth's Great Plan to Introduce Time Study into Surgery. *American Magazine.* New York. 48.

Devotes a good deal of attention to describing Gilbreth's personal appearance and characteristics and then goes on to say that after a year's investigation of the subject Gilbreth is of opinion that "scientific management applied within the time limit of actual surgical operations will cut down the ether minutes of a patient from ten to thirty per cent." No details are given.

Patch, D. (1916.) Time Study Eliminates Cost Details of Design. *Engineering Record.* New York. **73.** 749.

It was found that a good deal of time was taken in laying the wooden blocks of a floor. The process was time studied, and revealed that a particular method of filling the corners was responsible for the large amount of time taken by the operation. A new method was found for doing this process and time thus saved.

PENDLETON, C. & R. E. KENNEDY. (1914.) The Value of Saving Seconds in the Foundry. *The Foundry*. New York. **44.** 347. (Same article as in "The Transactions of the American Institute of Metals.")

Gives particulars of how a time study should be made in a foundry.

POTTER, Z. L. (1915.) Fixing Standard Time for a Bonus System. *Railway Age Gazette*, Mechanical Edition. New York. **89.** 192.

RANDOLPH, L. S. (1909.) The Principle of the Time Ticket. *Engineering Magazine*. New York. **37.** 209.

Gives examples of various types of time tickets and explains the way in which they should be used

REED, H. W. (1911.) A Time Study under the Taylor System. *American Machinist*. New York. **35.** 688.

Gives instructions as to the best way to make a time study. It was found that the rest period necessary to counteract fatigue in a machine shop varied between 20 and 80 per cent of working time, according to the nature of the job.

ROGERS, S. B. (1912.) Making Fewer Motions at Machines. *Factory*. Chicago. **8.** 268.

The article gives illustrations and details of improvements that have been made in the supply of material to, and the removal of the finished article from machines of various types.

Case 1.—Machine cutting and forming barstock. Originally material was dumped on the floor near the machine and when finished was again allowed to fall on the floor. Proper trucks were supplied and 27 cents per 1,000 parts were saved by the new method.

750,000 parts were made annually by this machine.

Case 2.—Woodwork shaping. A new method based on principles similar to Case 1 reduced the cost 22 cents per thousand. About 650,000 of the parts were made annually by this machine

Case 3.—Handling work at drawing press In the original method the material was supplied on the floor, lifted to machine, and greased by operator, passed through machine, and then thrown on the floor again. In the new method the material was supplied on tables, greased by an assistant and placed on machine. The operator passed it through machine and on to table on right-hand side.

$1·70 per 1,000 was saved by new method, 300,000 parts being the annual output of such a machine.

Case 4.—Describes work done at three adjacent machines. The method was for each operator to put the finished article on the floor for the next operator to pick up. The material was supplied on a truck and handled by means of a chute, with the result that $505 were saved annually on an output basis of 300,000

Case 5—Describes work on punch presses where material was supplied on floor and deposited there when finished. A pan chute and box were supplied and a saving of 30 cents per 1,000 was made, this equalled $255 annually.

SCHULZE, C. W. (1916.) Task System Applied to Executive Officers. *100%*. Chicago. **7.** 23.

SHEPARD, G. H. (1912.) An Analysis of Practical Time Motion Studies. *Engineering Magazine*. New York. **43.** 538.

Gives timings of certain engineering operations, and points out how time can be saved by doing two movements at the same time.

THOMPSON, S. E. (1913.) Time Study and Task Works. *Industrial Engineering & Engineering Digest.* New York. **13.** 347.

Advocates setting piece rates by time study and gives instructions of how to proceed.

THOMPSON, S. E. (1913.) Time Study and Task Work Explained. *Iron Age.* New York. **91.** 1010.

Deals with the general principles of time study.

TRAMM, K. A. (1920, May.) Uber Psychotechnische Bewegungsstudien an Strassenbahnnotbremsen. *Praktische Psychologie.*

An interesting article with illustrations of the use of the cyclegraph in judging the efficiency of a brake from the point of view of manipulation.

——. (1920, August.) Arbeitszeit und Ermudüng beim Taylor System. *Praktische Psychologie.*

A discussion of the Taylor system, pointing out the insufficiency of the amount of time allowed by Taylor to be added to shortest time for doing a job.

TRINKS, W. (1916.) Time Study for Efficiency in Steel Works. *Blast Furnace and Steel Plants.* Pittsburgh. **50.** 429.

VAN DENENTER, J. H. (1915.) Small Shop Time Studies. *American Machinist.* New York. **52.** 1025.

Encourages the small shop owner to pay attention to the question of time study and gives instructions of how to do time studies.

——. Wasted Intervals in the Small Shop. *Ibid.* 981.

Deals with the analysis of a simple lathe job and indicates the nature of time study.

(1916.) Teaching Shop Management by Motion Pictures. *American Machinist.* New York. **45.** 293.

An article indicating the use that can be made of motion pictures as a means of instruction. Illustrations are given. The result of motion study on the operations involved in using a small miller was that a boy was able to turn out 3,000 pieces per day, whereas previously a man had been able only to turn out 700.

(1916.) Sielberberg's Master Cronograph. *Automobile.* New York. **34.** 329.

A photograph and description of Sielberberg's Master Cronograph for use in time study.

(1915, November 19.) Photography and Industrial Efficiency. *The British Journal of Photography.* London. 750.

An article reprinted from *The Financier* of November 10, 1915. Describing the photographic methods adopted by Gilbreth in time motion study.

(1916.) Time and Motion Studies lead to Pneumatic Tools. *Compressed Air Magazine.* **21.** 7878.

An article suggesting that the putting in of screws, nuts, etc., should be done with pneumatic tools and not with the hand

(1911.) Motion Study. *Engineering*. London. **92**. 357–358.
An editorial criticising Gilbreth's methods. Points out the confusion that occurs from failing to distinguish between motion study proper and the introduction of labour-saving devices.

(1912.) Laboratory Motion Study. *The Engineering & Mining Journal*. New York. **93**. 344.
Advocates chemists in industrial laboratories using the latest appliances in order to save time.

(1913.) Micro-Motion Study. *Industrial Engineering & Engineering Digest*. New York. **13**. 1.
An article describing Gilbreth's methods and giving illustrations.

(1914.) Minimising Movements in the Foundry. *Industrial Engineering & Engineering Digest*. New York. **14**. 423.
An article indicating various methods of saving wasted labour in a foundry.

(1914.) Applying Motion Study to the Moulder. *Industrial Engineering & Engineering Digest*. New York. **14**. 423.
Gives instructions of how to commence motion study in a moulding shop and also an illustration of an improved moulder's bench. In one operation, the details of which are given, an operation was reduced from 5·34 minutes to 3·83 minutes.

(1915.) The Science of Management. *Financier*, Nov. 10th.
A general article dealing with Scientific Management and describing Gilbreth's and Taylor's methods.

(1915.) Motion Study and Time Study Instruments of Precision. *International Engineering Congress, Transactions of*. San Francisco. 473.

(1912.) The Taylor System in Government Shops. *Iron Age*. New York. **89**. 726.
The report of the Special Committee of the House of Representatives to investigate the Taylor and other systems of shop management.
The report deals with the various aspects of Scientific Management. It approves the standardisation of tools and the systematisation of the organisation of the factory, but it expresses grave doubts in respect to the methods of stimulation employed. It states that workmen "have made no serious complaints in respect to standardisation and systematisation, but that they have vigorously protested against stimulation on the grounds that it tends to injure their health through overwork.

(1912.) Human Elements in Scientific Management. *Iron Age*. New York. **89**. 912.
A series of letters from American employers of labour in criticism of the report of the Committee of the House of Representatives on the Taylor system. They are mostly in favour of stimulating the worker by some premium system of payment.

(1912.) Growing Applications of Scientific Management. *Iron Trade Review*. Cleveland, Ohio. **51**. 1119.
Gives an account of motion study in connection with braiding machines.

(1913.) *Literary Digest.* **46.** 227.

An illustrated unsigned article pointing out the use of the cinematograph in motion study. The time of a worker assembling a machine was reduced from 37 minutes to 8½ minutes.

(1915.) Time Study in Excavating and Handling Material. *Municipal Engineering.* Ind. **72.** 460.

(1911.) Measuring the Labourer's Worth. *Scientific American Supplement.* **72.** 83.

Mentions Dr. Jubert's experiments on vine cutters. There were two classes of vines to be cut. The pay for one was 60 centimes per thousand, and for the other 50 centimes. The woman complained that 60 centimes was not sufficient for the heavier work Dr. Jubert attached a dynamometer to the shears and found that the total effort expended in cutting the smaller vines was 110 kilograms, and in cutting the larger ones 266 kilograms, so that the pay for the latter, he claims, should have been 140 centimes per thousand and not 60 centimes

An experiment is mentioned which showed that the number of heart beats and expirations per minute were increased less when a certain routing operation was performed with a truck than when the same operation was done by hand.

(1913.) Micro-Motion Study. *Scientific American Supplement.* **108.** 85.

An unsigned article with illustrations describing Gilbreth's work.

(1915.) The Industrial Coach. *Scientific American.* **93.** 402.

An unsigned article explaining Gilbreth's methods and giving illustrations Mentions that Gilbreth reduced one girl's movements in handkerchief folding from 150 motions to 14 motions The increase in output was in the ratio of about fifty to fourteen.

(1921. March.) Motion Study. *Times Engineering Supplement.* 557.

An editorial article describing Gilbreth's methods.

(1916.) Standardisation of Time Study. *100%.* Chicago. 82

(1916.) Time Study Applied to Construction. *Ibid.* 84.

(1916.) Importance of Time and Motion Study. *Ibid.* 110.

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PREFATORY NOTE.

The *ease* with which a given task can be carried out has obviously an important and direct bearing on industrial efficiency and fatigue, and is influenced by many factors. So far as factory conditions are concerned, these may be conveniently divided into two categories, as follows :—

(*a*) the proper adjustment of conditions *extraneous* to the worker himself (such as arrangement of hours, length of spell, and the conditions of the workers' environment as regards temperature, lighting, ventilation, noise, &c.); and

(*b*) the proper development of the latent capacities possessed by the worker himself.

The former of these categories includes the points which have been dealt with in most of the reports hitherto published by the Board. The second comprises what may be termed the directly personal factors in human efficiency and can be treated from two points of view. First, vocational selection can be applied, and in this way a worker may be deterred from undertaking a task which is naturally uncongenial to him and may be transferred with little waste of time to one in which his natural aptitudes can be utilised. Secondly, means can be taken by the introduction of time and motion study to ensure that the completion of the task is carried through with the minimum expenditure of effort. Vocational selection, therefore, may be regarded as an antecedent to employment; motion study as a suitable method of training after employment has been accepted. For these reasons the Board have regarded both vocational selection and motion study as within their scope, and have already arranged for the publication of reports containing summaries of the work hitherto done in both subjects.*

As in the case of vocational selection, most of the work on time and motion study has been carried out in America, and in this country very little has yet been accomplished, but in the early stages of their existence the Board were brought into touch with one factory (an iron foundry), in whch a complete system of motion study had been in force for some years. The results, as published by the Board,† are seen to be very striking, and show that after the introduction of these methods both the output and the earnings of the men (in spite of a reduction in hours) rose enormously.

The present report embodies the results of an intensive investigation into the possibilities of applying motion study

* Muscio, B. (1921): Vocational Guidance (A Review of the Literature); *Industrial Fatigue Research Board, Report No* 12. Farmer, E. (1921): Time and Motion Study; *Ibid*, *Report No.* 14.

† Myers, C. (1919): A Study of Improved Methods in an Iron Foundry; *Ibid*, *Report No.* 3.

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methods in the buffing trade (the polishing of spoons and forks on a revolving wheel). The effects on output and fatigue are clearly indicated, and certain principles are suggested, not confined to the particular process investigated but immediately applicable to all trades on which the grinding or polishing of metal is carried on.

An inquiry of this kind, extending over a few months, can do little more than demonstrate lines for future development. The Board think that the results already obtained are strikingly suggestive, and hope that they may be considered of sufficient interest to induce the trades concerned to provide for further work in this direction by means of organisations formed within the trades themselves.

In conclusion, the Board desire to express their cordial thanks to Dr. R. S. Hutton, of Sheffield, for his continuous help and advice and for the facilities for investigation so generously afforded by him, and to Mr. Julius Frith, M.Sc., M.I.E.E., of Manchester, for expert assistance in carrying out part of the inquiry.

October, 1921.

MOTION STUDY IN METAL POLISHING

by

ERIC FARMER, M.A. (*Investigator to the Board*), assisted by R. S. BROOKE, M.C., M.A.

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1.—INTRODUCTION.

Metal polishing offers an excellent field for research in time and motion study, since the human factor is predominant. Machinery is indeed used in the form of a power driven wheel, but the actual manipulation of the articles by the operator is the controlling factor in the quality of the production, and the time it should take. In such diverse industries as cutlery, silver and electroplate, brass and aluminium holloware, the polishing processes account for a large fraction of the total labour cost of production; it is obvious therefore that the results of a research of this nature should have wide application.

In the present report, only one kind of polishing, namely the so-called buffing of spoons and forks is dealt with. Buffing consists of polishing certain types of metal ware by means of a revolving wheel to remove imperfections and scratches left

upon the face of the metal by previous processes. On account of its close association with the subsequent operations some attention is also given to the emery wheel filing or grinding of the edges of the spoons and forks.

2.—DESCRIPTION OF PROCESSES.

The buffing of spoons consists of the following processes :—

1. Filing.
2. Glazing.
3. Roughing.
4. Insiding.
5. Liming.
6. Inside grease dollying.
7. Outside grease dollying.
8. Inside colour dollying.
9. Outside colour dollying.

The buffing of forks consists of the following processes :—

1. Filing.
2. Glazing.
3. Roughing.
4. Graining.
5. Outside grease dollying.
6. Outside colour dollying.

Emery Filing is the process of grinding away against a compressed emery wheel the fash (*i e* the fringe of metal round the edges) left by the previous stamping or pressing processes.

Glazing (only occasionally adopted) consists in removing the file marks on the edges of spoons and forks by means of a wheel dressed with a mixture of glue and emery. In this country it is rarely employed whereas in France it is the standard practice. It undoubtedly obviates some of the harder work of the next operation of roughing.

Roughing is the process of removing imperfections and scratches from the surface and edges of the metal by means of a wooden wheel covered with a leather tyre and rotating at a high speed. The abrasive effect is obtained by allowing oily sand to fall between the wheel and the article being roughed.

Insiding is the roughing of the inside of the bowl on a small leather wheel varying in diameter according to the size of the spoon. The process is done in two parts, a smaller wheel being used for the bottom of the bowl.

Liming is a repetition of the work done by the smaller of the insiding wheels, but lime is used instead of sand to give an extra polish to this part of the spoon where the particles of metal are more compressed owing to the stamping process.

Inside grease dollying is the process of polishing the insides of the bowls by means of a small calico wheel dressed periodically with a mixture of tallow and rouge.

Outside grease dollying is the polishing of the remainder of the spoon by means of a calico wheel dressed as above. The wheel consists of discs of calico sewn together in three parts.

Inside colour dollying removes the greasiness left by the last process and imparts a high polish. The wheel is the same as for inside grease dollying but is dressed with white Vienna lime or other composition.

Outside colour dollying is the same as outside grease dollying, except that the calico discs comprising the wheel are not sewn together and the dressing is white Vienna lime instead of rouge and tallow.

Graining of forks is the process of removing with a thin leather disc the file marks between the prongs left by the filing process. As in roughing, sand is the abrasive used.

To avoid confusion the various subsidiary processes necessary for different patterns of forks and spoons are omitted. The object of this report is not to give a detailed account of buffing, but to deal with the general processes through which all forks and spoons must pass and to point out possible methods of improvement. All the subsidiary processes can be subsumed under the above divisions and will be affected by any improvement introduced.

3.—PRELIMINARY PLAN OF WORK.

Before any detailed investigation was started, visits were paid to a number of factories in Sheffield and Birmingham, where the spoon and fork industry is chiefly located. So far as could be gathered, no marked difference in general practice exists in this country, and the work is almost entirely carried out by women under the direction of men charge hands. At a later stage of the inquiry, a visit was paid to a large French factory, (an account of which is given in Appendix I), and it was at once noticeable that the industry had grown up on the two sides of the Channel with little or no exchange of views as to the methods of production.

Buffing as at present carried out is necessarily a dirty occupation as its chief process (*roughing*) necessitates throwing oily sand against rotating wheels. The workshops in some cases are badly lighted and confined in space, but most of this investigation was carried out in a works where the management had already done all they could think of to provide satisfactory working conditions and was eager to assist in applying any suggestion which might improve the conditions of work and reduce the discomfort of the workers.

Some of the earlier observations in this factory were devoted to determining the unproductive time, its distribution, and its causes, and this was done in typical cases of filing, roughing and dollying. An intensive study of this nature often leads, as in this case, to formulating a plan of work which can most easily or advantageously be followed.

Briefly stated, the main direction of the work decided upon was a comparative motion study of the several operations by different workers, and resulting, therefrom, the planning and trial of a training scheme. The absence of a single and accurate method for arriving at a standard polish made a scientific comparison of the work of different individuals or different works almost impossible. The invention of some method for quanti-

tavely estimating the degree of polish would be particularly valuable in connection with the training work, but it should, of course, be applicable to the different shapes and forms of articles being worked upon.

In the absence of any standards the loss of weight of the article being polished was found useful in the case of the coarser polishing processes, and eventually a recording wattmeter was employed to obtain an indirect measurement of the number and strength of the strokes taken by an individual worker for any section of the work. The use of the recording wattmeter in such manner offers a prospect of wide application in fatigue and motion study.

4.—EMERY WHEEL FILING.

At the commencement of the investigation in this factory, the firm were themselves engaged in experimental work to simplify the process of filing forks, with the object of dealing with a large Admiralty contract which had been received. An experimental shop with three operatives was available. Whilst taking a quite independent attitude, the investigators were able to collect data of considerable interest by comparing the different modifications of team work and bonus payment introduced by the firm. Such suggestions and investigations as were made by the investigators were limited to improvements in the actual movements, to devising eye screens and suitable seats, and finally to providing a contoured rest for the work which enabled the articles to be passed by the simplest possible motions across the face of the wheel.

It should be mentioned that throughout this study, only the filing of articles subsequent to their having been "set" or contoured was under observation. More generally the filing is performed in the flat, but similar principles would apply in this case also.

Time studies of the individual workers in the experimental shop, who had been chosen as possessing the requisite skill, shewed that the motions employed varied considerably. The three processes of "edging," *i.e.*, smoothing off the "fash" around the whole periphery of the article; "pronging," *i.e.*, cutting out the thin fin of metal between the individual prongs; and "pointing," or sharpening, took approximately the same time to perform on experimental small quantities. The operatives were then organised into a small team, the most skilled worker being chosen for the more difficult operation. It was found that the firm had already instituted a bonus system, depending on a basis output, for three workers, of 4 gross per day Admiralty forks, the earlier records having shewn rather under three gross.

At this stage a specially devised stool with inclined seat and foot rest was recommended and adopted, and as much of the workers' time appeared to be taken up in removing particles of grit from the eyes of their fellow operators, a "Triplex" Glass

Screen with side curtains was also supplied. The saving of time and annoyance was most noticeable. Subsequently, the actual handling of the article and its presentation to the face of the wheel was thoroughly studied, and particularly in the "edging," a great simplification of the process was introduced, details of which are set out below.

In the experimental shop, despite the interference caused by the investigators, and the constant trial of minor alterations, the three workers who had previously never attained the output of three gross per day between them, succeeded in finishing four gross the first day, and, within a week, an output of six gross per day was achieved.

The workers said that on account of the seating and eye protection their fatigue and discomfort were much less than under the old conditions; moreover, their earnings in the extreme case were 50 per cent. above the original datal standard.

Subsequently, the results of these experiments were applied in two other workshops of the same firm, where identical work was at the time being performed, but where no special provision had been made to study the comfort or movements of the operators. The experimental results in both cases were fully confirmed.

Similar time and motion study was subsequently carried out on spoons.

The following description explains the difference between the two methods of presenting the forks to the face of the wheels.

Old Method of Edging.

1. *Edges of Prongs.* The left hand side was done first, then the right. The fork was held concave side down and thrust across the wheel from the point to the base of the prong. A flat stand was used which made the motions for the left hand edge of prong different from those of the right hand. An upward movement of the elbow was made in doing the left-hand side and a downward movement for the right. The work was then allowed to cool.

2. *Edges of Handle.* The cool prongs held in right hand. The fork drawn across the face of the wheel from right to left, from prong base to handle end. The left thumb holding the work against the wheel. Either side could be done first.

New Method of Edging.

1. Work held by the handle in left hand began on side of prong concave side down. Fork passed across the wheel from end to end with cool prong between first finger and thumb.

2. Fork was then cooled in a shallow water trough large enough to hold six forks. Fork held by handle in right hand and begun

as above but on prong side with convex side down. Cool prong held in left forefinger and thumb. With the new stand the motions were not so pronounced in either case.

N.B.—Either side could be begun first according to the worker's wish to finish off the handle end right or left handed.

The other two members of the team were doing the pointing and pronging.

No alteration was made in their movements but their work was particularly adapted to a sitting position. In both cases a thin wheel is used to go between the prongs and a straight forward and backward movement is made.

The old stand consisted of a flat steel support $2\frac{1}{2}$ inches wide. The new stand has a saddle-shaped section. The top of the saddle is slightly flattened. The edges of the new stand are all rounded except that next to the wheel.

5.—AN EXPERIMENT IN SEATING IN OUTSIDE GREASE DOLLYING.

The present section contains an account of an experiment carried out over two periods of one week (from 22nd to 29th July and from 25th to 31st August 1920). During the former period the worker, an outside greaser dollier, worked standing; during the latter period the work bench was modified so that she could sit comfortably, and a seat was provided which she could use whenever she wished.

The seat was a four-legged stool without a back, and its dimensions were as follows :—

Height from floor of back of seat - - - -	2 ft. $6\frac{1}{2}$ ins.
,, ,, front ,, - - - - -	2 ft. 4 ins.
,, ,, footstool - - - - -	11 ins.
Seat - - - - - - - - - -	15 ins. by $11\frac{1}{2}$ ins.

To enable the worker to sit comfortably her bench was slightly modified and a footstool provided. The general effect being that of a kneehole desk with a footstool.

She was allowed to please herself whether she used her stool or not, and it was found that she usually stood up until the morning break and afterwards sat for the rest of the day. She was very comfortable on the stool and said that she was less tired at the end of the day than she used to be.

The worker selected for the experiment (henceforth known as Worker A) was a dollier of six years' experience. She was fairly strong and of average height and took a keen and intelligent interest in her work. Her methods appeared to be very rhythmic and she worked at a speed considerably faster than that of her neighbours. Thus in the dollying of table forks her average time per fork was 24·14 seconds while two of her fellow workers took 34·27 and 47·75 seconds respectively. She was not particularly

nimble fingered and her extra speed can be attributed to the following facts :

1. She did no unnecessary work.

2. Whenever possible she employed a long continuous stroke passing over the surface once only, instead of the numerous short jabbing strokes used by so many of the other workers.

Since during the whole period of the observation none of her work was ever returned as being unsatisfactory, it follows that a course of training for all workers with a view to eliminating unnecessary movements in each particular process, would do away with much wasted labour.

As a small instance of what can be effected in this way, the following is an example. On observation, Worker A was found to take on an average only four seconds to complete the third process (*viz.* the shanks of the handles) in dollying table forks, and her neighbour (Worker B) to take seven seconds. Their methods of work, however, differed; Worker A gave one stroke along the front of the shank, whereas Worker B, gave two strokes involving an extra turn of the fork. This was pointed out to B, and adopting this new method she cut her time down immediately to five seconds without any deterioration in the quality of her work. (*See* § 6 *Motion Study with Outside Grease Dolliers.*)

Although Worker A was told to disregard the investigator entirely, and to work absolutely naturally, his presence was found in practice to have a definite speeding up effect. Occasionally he left the factory for 15 or 20 minutes, and in almost every case her output during that period decreased. This decrease was equally noticeable whether she was standing or sitting.

Such alteration in the worker's normal speed cannot be obviated in experiments of this kind. An increased interest is brought in by the investigator's presence which naturally shows itself in the output of the worker. If, therefore, the output records obtained personally by the investigator during the period when seating was provided had been compared with others extracted from the factory books for a period when the investigator was not watching the worker, the results would not be comparable, for in the one case, there would be an increased output due to his presence which would be lacking in the other. In this experiment A's daily output record when standing and when seated was obtained in each instance by personal observation, and so the presence of the investigator, although it had a stimulating effect, constituted a common factor present in both cases and in no way detracted from the value of the comparison of the figures obtained.

To compare the two methods of work, two tests were used :—

(*a*) variations in the average half-hourly output throughout the day; and

(*b*) the hourly incidence of voluntary rest pauses throughout the day.

Variations in Output.—One of the chief difficulties of this investigation was the fact that a dollier works on a great variety of articles, all of which require to some extent different treatment. Output figures were obtained for the dollying of the following different articles :—Table forks, dessert forks, table spoons, dessert spoons, tea spoons, coffee spoons. These figures, which represent the time taken for the task regarded as a whole were, however, more or less valueless unless some accurate relationship could be established between the effort required to dolly each of these various articles. To determine this relationship, each of the operations necessary to outside grease dolly these various articles was timed, and the following were the average times taken by A to complete the processes. These timings are of the smallest divisible unit and not of the task as a whole.

	Time in seconds.
Coffee spoons :	
1st operation (edges) 6 at a time	1·03*
2nd ,, (shanks and bowls) singly	4·84
3rd ,, (handles) singly	4·38
Total	10·25
Tea spoons :	
1st operation (edges) 6 at a time	1·45*
2nd ,, (shanks and bowls) singly	4·90
3rd ,, (handles) singly	4·60
Total	10·95
Dessert spoons :	
1st operation (edges) 4 at a time	2·25*
2nd ,, (shanks and bowls) singly	8·34
3rd ,, (handles) singly	8·96
Total	19·55
Table spoons :	
1st operation (edges) 4 at a time	2·25*
2nd ,, (bowls) singly	5·50
3rd ,, (shanks) ,,	6·00
4th ,, (handles) ,,	8·80
Total	22·55
Dessert forks :	
1st operation (edges) 4 at a time	3·86*
2nd ,, (prongs) singly	6·13
3rd ,, (shanks) ,,	3·44
4th ,, (handles) ,,	7·00
Total	20·43
Table forks :	
1st operation (edges) 4 at a time	4·39*
2nd ,, (prongs) singly	6·00
3rd ,, (shanks) ,,	5·20
4th ,, (handles) ,,	8·55
Total	24·14

* For operations, in which several articles were treated simultaneously, the time taken is the average *per article, i.e.*, the total time divided by the number of articles treated.

Taking coffee spoons as the unit of measurement these figures show that the dollying of one table fork takes the same time (and therefore presumably requires the same effort) as the dollying of 2·35 coffee spoons. Similarly, one dessert fork is equal to two coffee spoons and so on.

A further factor that has to be taken into account in estimating output is the effect of periods (rest pauses and other stoppages) during which no productive work was done. For the purpose of the output records, these were divided into two classes :—

(*a*) Unnecessary stoppages.

(*b*) Necessary stoppages.

Under (*a*) were included all short pauses for conversation and actual idleness. These were counted in the half-hourly timings above referred to, and consequently they decreased A's output rate.

Under (*b*) were included all pauses to fetch work, to mend her dolly, and other unavoidable stoppages. Under this head also were included the periods when she left the factory. None of the pauses under (*b*) was included in the time spent on dollying articles, and so had no effect upon the output rate as given above.

Fig. 1 shows A's average output (reduced to a common unit and corrected for stoppages as already described) for each half hour during the day, the continuous line representing the period

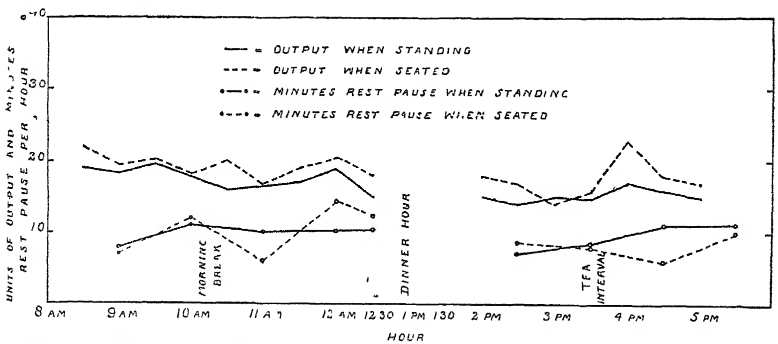


Fig. 1.—Output and voluntary rest-pauses of a worker when seated and standing

when she was standing at work, and the broken line the period when she was seated at work. The period represented by these curves (six days in each case) may possibly have been too short for the results to be absolutely reliable, but one or two points come out quite clearly.

1. The output when the worker is seated is higher than when she is standing. Thus the average half-hourly output throughout the day is 18·1 units when sitting and 16·3 units when standing.

2. Although the fluctuations in her output curve when she was seated are greater than when she was standing, yet there

seems to be more buoyancy in the former case. Thus in the morning the curve representing work sitting constantly reaches the standard of the first hour's work, and although it drops below it in the afternoon yet it exceeds it in one spurt at 4 o'clock. On the other hand, the curve representing work standing, except for two spurts at 12 o'clock and 4 o'clock, never touches the standard reached during the first hour's work of the morning.

3. Both curves rise at 12 in anticipation of dinner. That this rise is not maintained till 12.30 is probably due to the tendency to knock off work and clear up a few minutes before the actual dinner hour.

4. In both curves there is an immediate response to the tea interval, but in neither is the spurt maintained.

A further comparison between A's output when standing and her output when seated is given in Table I., and shows that her working speed was increased in every instance :—

Table I.—*Output of outside Grease Dollier* (a) *Standing,* (b) *Seated.*

Type of Article.	Standing			Seated.		
	Time Worked	Output.	Numbers Completed per Minute.	Time Worked.	Output.	Numbers Completed per Minute.
	Mins.			Mins.		
Coffee spoons -	312	907	2·9	49	144	2·94
Tea spoons -	639	1639	2·56	425	1118	2·63
Dessert spoons -	102	173	1·7	203	360	1·76
Table spoons -	322	414	1·28	68	108	1·58
Dessert forks -	245	291	1·18	139	216	1·55
Table forks -	90	105	1·16	516	648	1·25

Although the differences in speed are for the most part slight, the increased output in table spoons on a day's working is represented by one gross, and that in dessert forks by no less that 177·6 forks.

Rest Pauses.—During both periods of the experiment, A was allowed to take whatever rest pauses she liked, and, except for the morning and afternoon breaks of 15 minutes each and the dinner hour, no pauses were enforced.

The average rest-pause incidence has been plotted in Fig. 1, the circles on the continuous line being the hourly incidence when standing, and the circles on the broken line the incidence when seated. These graphs take account of all rest pauses except the authorised breaks. These authorised breaks have been dealt with in the following manner :—

If, for instance, A had 15 minutes break from 10 to 10.15, and during the remainder of the hour took nine minutes rest

pause, that is, 9 minutes pause in 45 minutes, then her rest pauses for the hour 10 to 11 have been reckoned as 12 minutes.

The curves show that the average rest pauses taken per day apart from the authorised breaks amount to 87 minutes when standing and 85 minutes when seated. It is interesting that over two separate periods the average duration of the rest pauses taken should approximate so closely, but too much importance should not be attached to the actual fluctuations in the rest-pause incidence as this was governed so much by circumstances outside the worker's control, *e.g.*, the adjusting and mending of her dolly, taking unsatisfactory work to be rebuffed, fetching work and waiting if none were ready. At the beginning the worker received varying quantities at a time, but towards the end of the inquiry the work was given out in boxes containing three dozen of a particular article. This was probably an improvement, and the fetching of fresh work after the completion of each three dozen articles ensured that the worker got a rest at more or less regular intervals. Probably this natural pause of two or three minutes at the completion of a task is sufficient rest for the dolliers as the work is not heavy. Any enforced rest pause in the middle of a task would probably be a worry to the workers, and consequently a strain upon them.

Since these data were collected, other outside grease dolliers have been provided with stools. They all speak highly in their favour and the seats are in constant use, which is a very sure sign of the success of the experiment. From every point of view it is a step of the very greatest value, for it not only diminishes strain and fatigue but also by avoiding the direct contact of the worker with the floor, reduces to some extent the evil effects of vibration.

The movements involved in colour dollying are similar to those in outside grease dollying, and seats which are in constant use, have now been provided for the latter processes.

6.—TEAM WORK IN OUTSIDE GREASE DOLLYING.

In the course of the previous experiment in seating (§ 5), some data were obtained enabling a comparison to be made between the output of an operative when collaborating with another operative and her output when working alone.

At the beginning of the experiment, A was working with B, the latter doing the first operations and then passing on the articles to A to complete. It was then noticed that A was the faster worker and was in consequence continually delayed, so they were stopped and asked to work separately. During the period when they collaborated (9.15 a.m. on the 22nd July to 3 p.m. on the next day their output figures were as follows :—

Table II.—*Output of Two Dolliers working together.*

Article.	Time worked.	Output.	Average Number per Minute.
Tea Spoons - - -	313′ 20″	1021	3·25
Coffee Spoons - - -	80′ 20″	331	4·12
Table Forks - - -	173′ 00″	280	1·62

The average number of articles completed each minute by each worker was therefore 1·62 tea spoons, 2·06 coffee spoons, 0·81 table forks. Afterwards working by herself without a stool A's average output per minute was 2·56 tea spoons, 2·9 coffee spoons, 1·16 table forks. Hence the following table of comparison can be drawn:—

Table III.—*Output of a Dollier working* (a) *with another Dollier and* (b) *by herself.*

Article.	Output per Minute.	
	A working with B.	A working by herself.
Tea spoons - - -	1·62	2·56
Coffee spoons - - -	2·06	2·9
Table forks - - -	0·81	1·16

The above figures in themselves merely illustrate the well-known fact that the pace of a team is the pace of its slowest worker, but a comparison of the curves in Fig. 2 brings out quite

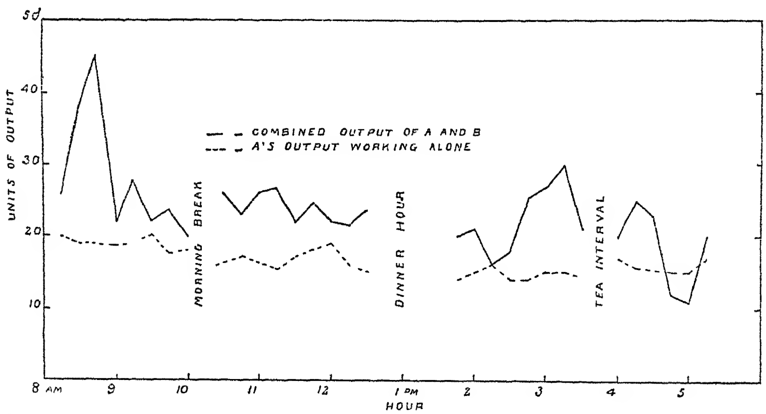


Fig. 2.—Hourly output of two workers working together and of one working alone.

clearly another argument in favour of each worker working separately. When working together the output curve zig-zags up and down continually, but when working separately a much flatter curve is obtained. This irregularity in the output curve when A and B were working together is due partly to one or other of the workers having to wait for work to be passed on, and partly to a tendency to discuss any peculiarity in the work which is of mutual interest. When the peculiarity concerns the individual only there is no need to discuss it.

7.—MOTION STUDY WITH OUTSIDE GREASE DOLLIERS.

A brief study of the movements employed by outside grease dolliers was sufficient to make plain that there were enormous variations both in the movements and methods employed by different workers, and that in consequence of this some experienced and so-called skilled workers took almost twice as long to do the same job as others. These slow workers seemed to be possessed by the fear lest their work should be returned to them as unsatisfactory, and so, to avoid this, they went over the same surface time after time. Probably the chief reason for this tendency to over polish was the impossibility of telling whether an article has been efficiently grease dollied until it has been coloured. There had been no organised system of instruction, and it had not been pointed out to the workers that the surface of the spoon or fork as it comes to them from the roughers is a standard surface, and that therefore some standard number of strokes is sufficient to polish that surface, all effort beyond the required number of strokes being wasted.

In order to remedy this it was determined to systematise the effort required, and in this respect advantage was taken of the fact that the methods of Worker A, a particularly intelligent and quick worker, whose output and rest pauses had been already observed, were used to a very great extent by the head dollier in the factory, who was afterwards persuaded to train the slower and inefficient workers. The standard movements which the workers were advised to adopt are given on p. 18. As they became more skilled some of them developed minor individual variations, and a few dolliers of long standing could not be persuaded to cut down their movements to this minimum, but, on the whole, as will be shown by a comparison of their times, working under their old methods and under the new, considerable progress was made.

Systematised Movements used for Training.

Baguette Tea Spoons. (*See* Plate A.)

1*st Operation.*—Six strokes. Take six tea spoons and give one long stroke on edge of shanks holding them horizontal to wheel. Then run the wheel once along the edges of the handles, round the end of the handles, back along the other edge and finish with another long stroke on other edge of shanks. Then still holding six, do the back of the bowls with three separate strokes, or one continuous up and down stroke, dropping each spoon in turn as it is finished.

2*nd Operation.*—Three strokes. Take each spoon singly and give one stroke along front of shank. Then reverse the spoon and give one stroke along back of shank, finishing on left shoulder of bowl, Then turn the spoon and give another stroke along shank, finishing on right shoulder of bowl.

3*rd Operation.*—Three strokes. Take each spoon singly and give one stroke along either side of the baguette down front of the handle, then turn spoon and give one stroke along the back of the handle.

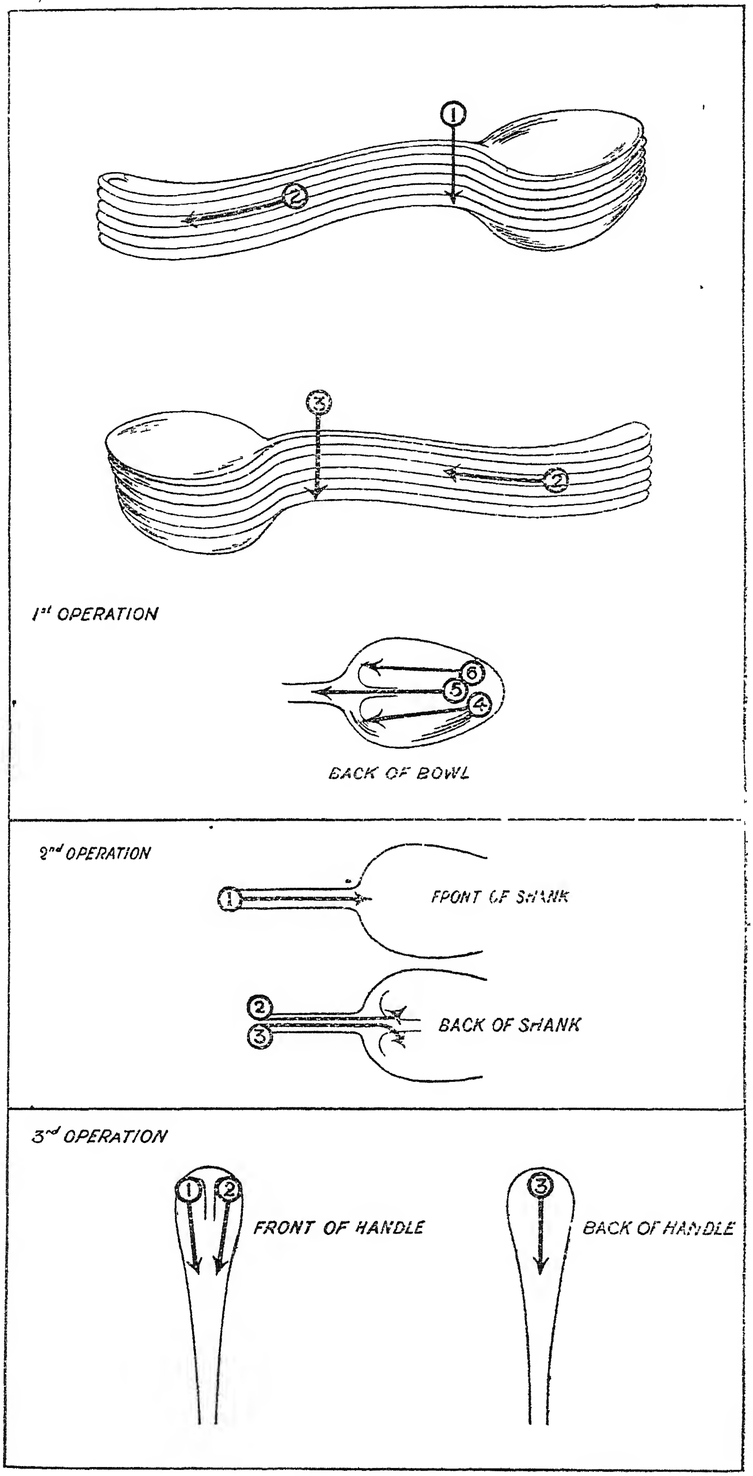
Baguette Table Forks. (*See* Plate B.)

1*st Operation.*—Five strokes. Take four table forks and give one long stroke on edge of shanks, holding them horizontal to wheel. Then run the wheel once along the edges of the handles, round the end of the handles, back along the other edge, and finish with another long stroke on the other edge of the shanks. One stroke along the edges of the prongs on each side.

2*nd Operation.*—Five strokes. Take each fork singly, give one stroke left to right along the solid concave portion of the front of the prong and one stroke right to left. Then one stroke diagonally left to right across prongs and one stroke diagonally right to left across prongs. One stroke straight up the back of the prongs.

3*rd Operation.*—Three strokes. Take each fork singly and give one stroke along front of shank, then reverse the fork and give one stroke along back of shank finishing on the left shoulder of prong, then turn the fork and give another stroke along back of shank, finishing on right shoulder of prong.

4*th Operation.*—Five strokes. Take each fork singly and give one stroke down the handle on each side of the baguette or ridge, and a third stroke down centre of handle. Turn the fork and give two strokes along the back of the handle.



TEA SPOONS
PLATE A

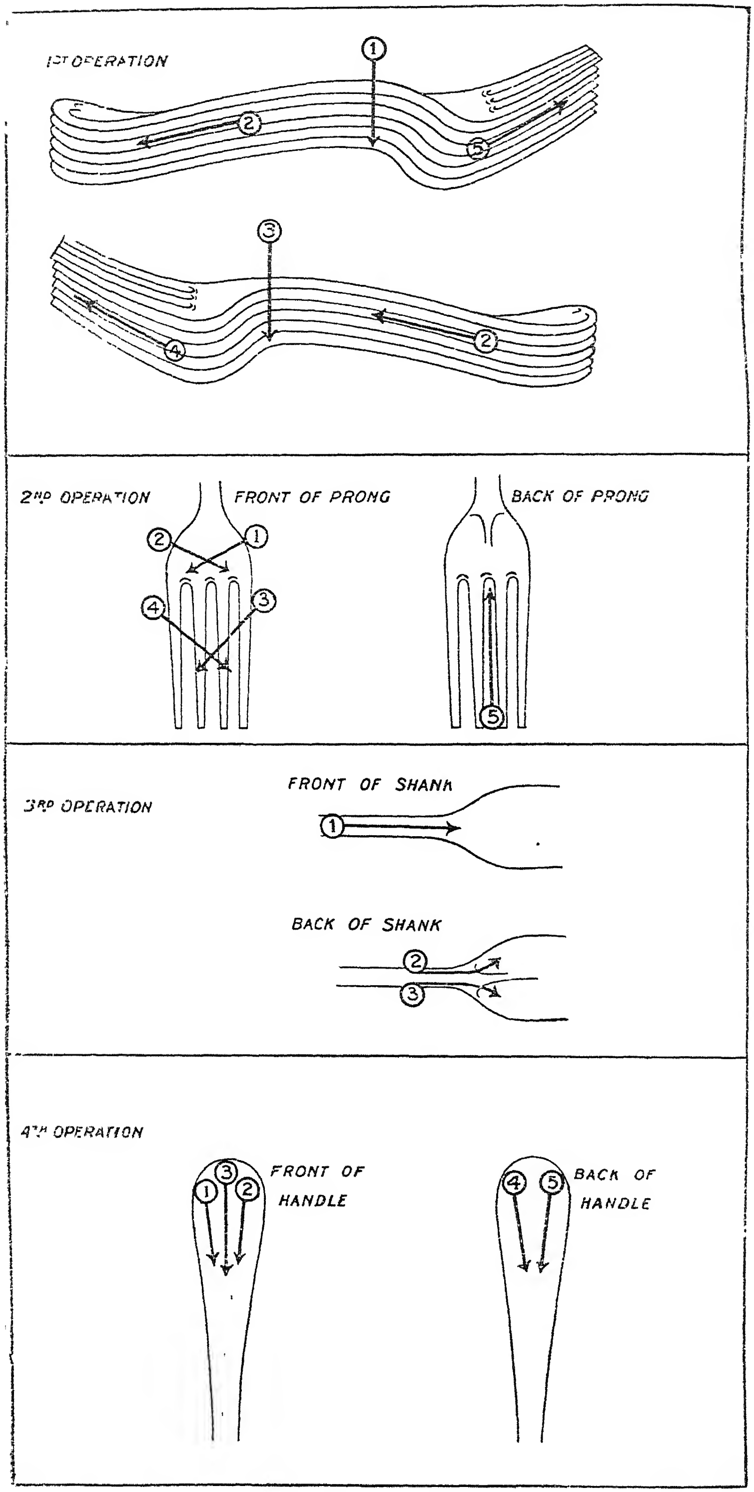


TABLE FORKS
PLATE B

The results of the old and new methods were as follows :—

Worker C.

Over three years' experience as a dollier. An intelligent woman but somewhat conservative. She was very sceptical when first spoken to, but when the forewoman dollier corroborated what was said, she altered her methods considerably, though she was still inclined to over-polish.

Table IV.—*Output of Worker C (Table Forks).*

—	Old Method.		After Instruction.	
	Strokes.	Time taken. (secs.)	Strokes.	Time taken. (secs.)
1st operation, holding 4* -	—	3½	—	3
2nd ,, singly -	8	11½	5	7½
3rd ,, ,, -	7	9	4	6½
4th ,, ,, -	12	19	5	9
Total (per fork) -	—	43	—	26

Worker D.

A worker of nearly nine years' experience. She put an enormous amount of energy into her work, and polished every surface over and over again. She, too, was somewhat conservative in outlook, and her attitude of mind was, to use her own expression, "I am not going to have any of my work sent back." She was slow in her movements as well as wasteful of her energy, but the quality of her work was excellent.

Table V.—*Output of Worker D (Table Forks and Tea Spoons).*

—	Old Method.		After Instruction.	
	Strokes.	Time taken. (secs.)	Strokes.	Time taken. (secs.)
*Table Forks.**				
1st operation, holding 4* -	—	7¼	—	5
2nd ,, singly -	8	14	6	9
3rd ,, ,, -	6	11	5	9
4th ,, ,, -	7	12½	5	10
Total (per fork) -	—	44¾	—	33

* *See* footnote on page 12.

—	Old Method.		After Instruction.	
	Strokes.	Time taken. (secs.)	Strokes.	Time taken. (secs.)
Tea Spoons.				
1st operation, holding 6* -	—	6	—	6
2nd ,, singly -	5	6½	4	5
3rd ,, ,, -	8	11½	4	4½
Total (per spoon) -	—	24	—	15½

Worker B.

A quick nimble-fingered girl of nine months' experience. A fast but unsteady worker. Not strong. Worked next to Worker A and copied her methods.

Table VI.—*Output of Worker B* (*Table Forks*).

—	Old Method.		After Instruction.	
	Strokes.	Time taken. (secs.)	Strokes.	Time taken. (secs.)
1st process, holding 4* -	—	2½	—	2½
2nd ,, singly - -	5	6½	5	6½
3rd ,, ,, - -	4	7	3	5
4th ,, ,, - -	5	8½	5	8½
Total (per fork) -	—	24½	—	22½

Worker A.

A worker of six years' experience. She worked very intelligently and the new system was largely modelled on her methods. Her method of dealing with spoons differed from any other worker, for, instead of doing the edges and bowls together and then the shanks and handles separately, she did the edges first, then combined the shank and bowl, and finally did the handles. The suggestion was made that she should try the following methods :—

First, pick them up by sixes and do the edges and bowls, then pick them up singly and do the shanks and handles, thus picking her work up only twice instead of three times, as under the normal arrangement.

The result of this experiment was rather curious, for the average time taken for each tea spoon under the new method was 15 seconds

* *See* footnote on page 12.

as against 11 seconds under her usual method. But her average time for three dozen tea spoons of various types was 12 minutes 35 seconds, whereas her average time under the old methods for completing three dozen tea spoons of all types was 13 minutes 40 seconds, and so the time she lost in actually polishing the spoons under the new method was more than made up by the time saved in only picking her work up twice instead of three times. She complained, however, that she burnt her fingers on the shanks when working this new method, and the experiment was not continued.

The slower actual working time of A when picking up tea spoons only twice under the new method, was undoubtedly due to the fact that she was burning her fingers, and so making her clumsy in the manipulation of the tea spoons.

An experiment in the provision of a glove for outside grease dolliers was subsequently tried with Worker G, a young girl who had been given a specialised course of training in the movements of dollying. She was given an old right hand wash leather glove and timed while dollying table forks and tea spoons.

When using the glove for table forks she first did the edges by fours. She then picked up each fork separately and completed the dollying of the prongs, shank and handle without putting it down, thus picking up her work twice instead of four times under the usual method.

When using the glove for tea spoons, she first did the edges and bowls by sixes, and then picked them up separately and did the shank and handle, thus picking her work up only twice instead of three times.

In both cases the glove was used as a protection against the heat of the spoon or fork and not as a protection against the rubbing of the wheel. On her left hand she had the usual finger bandages as a protection against the wheel. The experiment resulted as follows :—

Table VII.—*Output of Worker A (Table Forks and Tea Spoons).*

Without Glove.			With Glove.		
No. of Articles.	Time Taken. (min.)	Speed.	No. of Forks.	Time Taken. (min.)	Speed.
Table Forks.					
36	22	Normal.	36	$18\frac{1}{2}$	Normal.
			36	19	Normal.
36	17	Working as fast as she could.	36	$15\frac{1}{4}$	Working as fast as she could.

Without Glove.			With Glove.		
No. of Articles.	Time Taken. (min.)	Speed.	No. of Spoons.	Time Taken. (min.)	Speed.
Tea Spoons.					
36	13	Normal.	36	$11\frac{1}{2}$	Normal.

When working as hard as she could, her work was efficiently done in both cases, but she did not waste a moment on either occasion and literally raced the whole time.

A considerable saving of time was therefore, shown in all cases, and the provision of some sort of glove is at least worth serious consideration. Worker G stated that this wash leather glove was not clumsy nor uncomfortable in use, but that when she was working fast on table forks she was inclined to feel the heat of the prong through the glove when dollying the handle. This particular glove split across the thumb before the end of the day, and it is probable that wash leather is not a strong enough material. It would undoubtedly be difficult to find a material that has the strength and pliability required, but if this could be done a glove of this description would be very useful.

Worker E.

A worker of about a year's experience. Somewhat slow but very willing and anxious to learn.

At first she picked up six tea spoons, dollied the edges of the handles and put them down on the bench until the edges of all 36 had been done. Then she picked them up again by sixes and did the back of the bowls. She was asked to do the edges of six and then go straight on to do the back of the bowls of those six, before picking up the next six to do the edges. As a result she did the edges and bowls together in slightly faster time than the previous two movements, and saved all the time previously wasted in picking up the spoons afresh.

Later when working on mocha spoons she picked up the work for edging and bowls from the right and threw it when completed across herself to the left. She was persuaded to keep her work on the left and throw it to the right, and she at once reduced her time on nine mocha spoons from 56 seconds to 40 seconds.

On tea spoons, by eliminating an unnecessary second stroke along the front of the shank, the time taken was reduced from 4 seconds to $3\frac{1}{2}$ seconds. On table forks, by persuading her to adopt the standard movements for the edges her time per four forks was reduced from an average of 26 seconds to an average of 17 seconds, and in the same way the time spent upon the prongs was reduced from an average of $10\frac{1}{8}$ seconds per fork to an average

of 6½ seconds per fork. In all cases the quality of the work under the new method was in every way as satisfactory as under the old method.

Novices F and G.

Some ten days before this scheme was started two new dolliers arrived in the shop. They had neither of them had any experience of this type of work, but both were very keen and intelligent, and very young, Worker F being aged 15½ and Worker G 14, though she was exceptionally strong and big for her age.

They were given practically no instruction in dollying, and for ten days were trying to pick it up as best they could. They made a little progress, but naturally had no idea of the movements or effort required.

Table VIII. compares their method of dollying table forks after they had been at the factory for a week with their method after one day's tuition with the forewoman dollier.

Table VIII.—*Output of Novice F (Baguette Table Forks).*

—	Before instruction.*	After instruction.	
	Time Taken. (secs).	Strokes.	Time Taken. (secs.)
1st process, (4 at a time)†	16¼	—	4¼
2nd ,, (singly)	19	5	7
3rd ,, ,,	10	4	5
4th ,, ,,	25	5	11½
Total	70¼	—	27¾

Table IX.—*Output of Novice G (Baguette Table Forks).*

—	Before Instruction.	After Instruction.	
	Time Taken. (secs.)	Strokes.	Time Taken. (secs.)
1st process, (4 at a time)†	13	—	5½
2nd ,, (singly)	24	5	8
3rd ,, ,,	10½	4	7
4th ,, ,,	34	5	11
Total	81½	—	31½

* Their strokes before training were too many and too confused to count.

† *See* footnote on page 12.

After this short instruction they had not quite adapted themselves to the proper movements. They were still somewhat slow, and, owing to the want of physical strength and practice, had occasionally to give an extra movement. Their gradual and steady improvement under and after tuition is brought out perhaps even more strikingly by the figures of their daily output during this period, expressed in percentages, the average output of each novice being taken as 100.

Table X.—*Output of Novices F and G during Training.*

Day of Week.*	Percentage Output.					
	1st Week.		2nd Week.		3rd Week.	
	F.	G.	F.	G.	F.	G.
Monday	46	15	74	—†	140	142
Tuesday	94	43	92	—†	151	133
Wednesday	33	50	125	135	—	—
Thursday	43	—†	158	140	—	—
Friday	64	—†	181	142	—	—
Average	*56*	*36*	*126*	*139*	*146*	*138*

These figures prove conclusively that a beginner, given adequate training, can become an expert dollier within a very few days, but that left to herself, without proper instruction, she probably will never become highly skilled, and will continue all her life to waste her energy on unnecessary and unproductive movements.

The establishment in every factory of a training system under which all workers should undergo a course of training before being allowed to work by themselves, seems therefore to be of the greatest importance.

8.—ROUGHING.

The study of the methods of outside grease dolliers had shown that the majority of dolliers wasted a great deal of time and energy by the employment of unnecessary movements, and that by limiting the number of strokes and systematising the methods of work, the output per individual could be considerably improved without either increasing the fatigue of the worker or lowering the quality of the work done.

It was, therefore, decided to study the methods employed by the roughers, in order, if possible, to introduce some similar

* Omitting Saturdays. † Employed on roughing.

system in this branch of the work. The problem presented was, however, rather more complicated than before. The dollier receives a theoretically perfect article and is only required to give it a standard polish, which can be done with a given number of strokes; the rougher receives the spoon or fork as it is turned out by the presses or stamping machines, untouched except for the filling which has been done round the edges. To a limited extent these spoons or forks are also similar to each other, for a flaw in the die will be reproduced in all the articles struck upon it, but, in addition to these flaws running through whole batches, each spoon or fork is liable to its own peculiar faults due to the imperfections of the metal itself. Hence, the prescribing for each portion of the spoon or fork of a definite number of strokes which should not be exceeded was at once recognised to be impracticable, but it was hoped that a study of roughing might provide information which would be of assistance in reducing unnecessary labour.

With this object in view a systematic study was made of the methods of all the roughers in the shop in roughing a given task, namely, three dozen dessert spoons of the baguette or ridge pattern. The time taken by each girl to perform this task was noted, the number of strokes per spoon were counted, and the amount of metal removed was discovered by weighing each three dozen spoons before and after roughing.

The following table giving particulars as to the work of 26 roughers shows that there are large differences both in the time taken, the strokes made, and the weight of metal removed. In addition, observation showed that no two workers roughed the various parts of the spoons in precisely the same order, but that each worker had her own little idiosyncracies, some doing the work almost entirely with their arms, others using a swaying motion of the body so as to bring the weight of the body behind the stroke, and others combining their body and hand movements. Furthermore, different movements presented varying difficulties to different workers.

Table XI.—*Characteristics of Twenty-Six Workers Roughing three dozen baguette dessert spoons.*

Worker's Number.	Total time Taken. (min.)	Strokes per Spoon.	Weight removed per 3 doz. Spoons (oz. troy).
1	51	71	1·6
2	52½	61	1·3
3	56	89	1·0
4	61½	90	1·7
5	62½	54	1·4
6	68	64	1·9
7	71	74	1·3
8	73	76	2·2
9	74	82	1·4

Worker's Number.	Total Time taken. (mins.)	Strokes per Spoon.	Weight removed per 3 doz. Spoons (oz. troy).
10	74½	83	1·6
11	75	71	1·7
12	79	97	2·0
13	80	106	1·2
14	82	105	1·6
15	86½	95	1·8
16	87	102	2·0
17	92	114	2·2
18	92½	107	1·8
19	96	88	1·2
20	126	128	1·4
21	128	119	2·2
22	138	167	2·2
23	148	137	2·8
24	150	131	2·3
25	154	165	1·5
26	261	196	1·9

This table shows that there is a general tendency for the slow worker to take more strokes than the fast worker, and in a less marked degree for the amount of metal removed to vary directly with the number of strokes. This may be differently expressed by saying :—

The first five workers took on an average 76 strokes and removed 1·4 ozs. of metal.

The second five workers took on an average 76 strokes and removed 1·7 ozs. of metal.

The third five workers took on an average 95 strokes and removed 1·7 ozs. of metal.

The fourth five workers took on an average 108 strokes and removed 1·7 ozs. of metal.

The fifth five workers took on an average 144 strokes and removed 2·0 ozs. of metal.

The correlation between fewness of strokes and shortness of time taken for the task is $+ 0\cdot89 \pm \cdot12$. The correlation between smallness of weight removed and shortness of time for the task $+ 0\cdot46 \pm \cdot10$. The correlation between fewness of strokes and smallness of weight removed is $+ 0\cdot45 \pm \cdot10$.

An interesting incident occurred during these experiments. The time for Worker No. 12 when she was first timed was 105 minutes, the number of strokes employed was 157, and the weight removed was 1·8 oz. It subsequently transpired that this worker was feeling unwell at the time of the observation and she asked some time after if she might be timed again. She was a worker of many years' experience, and was quite convinced that she always employed the same number of strokes, and that they were the fewest possible if the work was to be satisfactory. She thought that if she were timed again she might be able to reduce her time, but was certain she could not reduce the number of her strokes. The results of the second timing were that she did the work in 79 minutes, the strokes

employed per spoon were 97, and the amount of metal removed was 2 ozs. The probable explanation is that this worker when first timed was in a fatigued condition, which naturally increased the time taken for the task, but in both cases she undoubtedly thought she was doing the same number of strokes, though this was not so. This seems to suggest that the number of strokes taken by a worker tends to increase as fatigue increases.* The worker is conscious of the increased fatigue but not of the increased number of strokes.

An instance of inattention tending to multiply strokes was provided by No. 23. Before the dinner hour this worker had been doing the back of the shank and half the bowl of each dessert spoon in an average of 15 strokes. After dinner she arrived back with an enormous sweet in her mouth, so large, in fact, that her attention was almost entirely occupied in preventing it falling out. The result was that it now took her 25 strokes on an average to do the same portion of the spoon. When the sweet was eventually disposed of she did the work in the same number of strokes as before dinner.

The study of the methods of these 26 different roughers made it clear that a very unsatisfactory state of affairs existed, and showed that there was urgent need for a training scheme which would in the first place teach the roughers the best method of work, and in the second place would focus their attention on their work.

Since even the most experienced roughers had no idea of the number of strokes they made in roughing each portion of an article, this had first to be determined for them. Accordingly three experienced workers who roughed in a good easy style were studied on the following articles :—Tea spoons, dessert spoons, table spoons, dessert forks and table forks—all of the baguette or ridge pattern. An average was then taken of their strokes, and one or two added to the number on each portion to make the standard more accessible to the indifferent worker.

Instruction cards X and Y as on p. 30 were then printed and pinned upon the bench in front of each worker.

These cards were explained to every worker, and those girls who took more strokes than suggested were told to try and reduce them, while those who took fewer strokes were advised to make no alteration in their methods so long as their work was properly done. The order laid down was not insisted upon, but its advantages were explained to all. It should be noted that the number of strokes on the handle edges and edges of the bowl in the case of dessert and table spoons and forks has been multiplied by four, and in the case of tea spoons by six, as it is a general practice to do the edges of four of the former, and six of the latter together.

These instruction cards were successful in that they interested the workers, although the more experienced roughers were

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* *See* § 10, *An experiment with Wattmeter.*

INSTRUCTION CARD X.

TABLE SHOWING NUMBER OF STROKES GENERALLY REQUIRED ON SPOONS (BAGUETTE PATTERN).

Suggested Order.	Tea Spoons.	Dessert Spoons.	Table Spoons.
Edges of handles - - - - -	36	36	42
Front of handles - - - - -	8	10	12
Back handle - - - - - -	4	3	6
Back shank and ½ bowl - - -	10	12	18
Back of bowl - - - - - -	8	10	13
Edges of bowl - - - - - -	10	10	11
Bowl mouth and front shank - -	8	12	13
Shoulder and shank edges - -	10	12	14

The above are the number of strokes generally required on the surfaces of each spoon, and on the edges of each six teaspoons, and of each four dessert, and each four table spoons.

The whole of each surface should be covered by the above number of strokes, then look at the work, and unless you see a fault, further strokes are unnecessary.

Read down each column, not across.

Remember slow hard strokes are better than quick soft strokes.

INSTRUCTION CARD Y.

TABLE SHOWING NUMBER OF STROKES GENERALLY REQUIRED ON FORKS. (BAGUETTE PATTERN).

Suggested Order.	Dessert Forks.	Table Forks.
Edges of handles - - - - -	36	42
Front of handles - - - - -	10	12
Back of handles - - - - -	5	6
Back of shank and back of shoulders -	6	8
Front of shank - - - - - -	5	6
Edges of prongs - - - - -	20	22
Front of prongs - - - - -	8	10
Back of prongs - - - - - -	4	4
Edges of shanks and shoulders - -	10	10

The above are the numbers of strokes generally required on the surface of each fork and on the edges of each four dessert and table forks. The whole of each surface should be covered by the above number of strokes then look at the work, and unless you see a fault, further strokes are unnecessary.

Read down each column, not across.

Remember slow hard strokes are better than quick soft strokes.

sceptical about their utility; still, the mere fact that they began to count their strokes in an effort to prove that the number laid down was inadequate, resulted in their taking a more intelligent interest in their work, and so, in spite of themselves, they began to do away with many unnecessary strokes. The immediate improvement that resulted may be judged by the fact that the roughers' output during the week following the posting up of these cards improved by 13 per cent.

Any further interference was thought inexpedient with the really experienced roughers, but a week's course of training for as many as possible of the semi experiened was decided upon. This course of training was under the immediate supervision of the investigator, while the best rougher in the shop was employed as demonstrator and technical adviser in such matters as rosining the buff, working in a new buff, pegging a buff when the leather worked up from the wooden wheel, &c.

This combination of a demonstrator and an instructor is very essential, for in the majority of cases, the foreman or forewoman rougher, however skilful he or she may be, have not the power of explaining their methods to others, while the beginner is incapable of learning by mere observation the best methods of work.

Twelve girls with some previous experience were passed through this training school. They came four at a time, and at the end of a week were passed on to a neighbouring bench of spindles so that they could be helped whenever necessary, and subjected to a certain amount of supervision.

Table XII gives a comparison before and after training.

Table XII.—*Characteristics of Twelve Workers roughing three dozen baguette dessert spoons (before and after Instruction).*

Worker.		Time taken. (minutes.)		Strokes made.		Weight recorded (oz.)	
Number.	Experience. (Months)	Before Instruction.	After Instruction.	Before Instruction.	After Instruction.	Before Instruction.	After Instruction.
10	16	74½	69	83	69	1·6	1·6
15	10	86½	72	95	76	1·8	1·5
5	5	62½	75	54	74	1·4	1·8
21	10	128	77	119	88	2·2	1·4
25	6	154	78	165	64	1·5	1·8
6	15	68	88½	64	51	1·9	2·4
19	12	96	91½	88	88	1·2	1·8
22	9	137	99	167	98	2·2	1·8
26	6	261	99½	196	84	1·9	1·5
24	10	150	105	131	92	2·3	1·5
20	10	126	106	128	103	1·4	1·5
23	10	148	113	137	87	2·8	2·4
Average for all -		126	89	119	83	1·85	1·75

The correlation of strokes and time before training is $+0 \cdot 95 \pm \cdot 01$ and after training $+0 \cdot 67 \pm \cdot 11$. This drop in correlation is probably accounted for by the fact that the trainees were encouraged to pay special attention to the reduction of strokes, and to disregard output.

The number of strokes per spoon was reduced from an average of 119 to an average of 83, and the average time was reduced from 126 minutes to 89 per three dozen spoons. If the same relationship is assumed to exist between the number of strokes and the time, the time should have been reduced to 87 minutes instead of 89. The fact that this is not the case seems to show that speed is one of factors as well as fewness of strokes making for high output. This speed factor played a smaller part in the girls' work during the period of training, their attention being mainly directed to an endeavour to decrease the number of their strokes. If a permanent decrease in the number of strokes can be obtained, it may perhaps be assumed that after the period of training the correlation between the strokes and time will be somewhat similar to that which was found to exist before the period of training.

If the average earnings for the three weeks preceding training be taken as 100, their average earnings for each of the three weeks following training is 127, 126, 136½ respectively. This increase is advantageous both to employer and employee, as the former is able to produce more from his plant, and the latter, since they were employed on the piece-rate system, increased their earnings.

Both the stroke and weight curves were flatter after training than before; the strokes varied before training between 54 and 196, and after training between 51 and 103. The weight removed before training varied between 1·2 oz. and 2·8 oz., and after training between 1·4 oz. and 2·4 oz.

In only two cases (Workers Nos. 5 and 6) has training had the effect of apparently slowing down the working speed and increasing the number of strokes. The reason for this was that these are both very vigorous workers who, before training, used to work at very high pressure with a great expenditure of energy, for short periods, and then took a long rest period for recuperation, during which, incidentally, they used to interfere with the work of their neighbours. They were persuaded to adopt more rhythmic and less jerky strokes, and, as a consequence of this, they were able to work much more steadily, and their weekly output increased by 42 per cent. and 27½ per cent. respectively, although their actual time for completing a given short task was somewhat longer.

Sufficient has been said to show how valuable to employer and employee alike a well-directed training scheme may be, and we can now pass on to consider the main principles upon which training in roughing should be based.

Perhaps the most noticeable difference between an expert, and an inexpert rougher, is the extreme ease with which the former works. There is none of the hurry and effort combined with vigorous body swing that is so marked a characteristic of many junior workers. The highly-skilled rougher does not appear to be working hard; she makes her strokes with slow heavy rhythmic movements, but yet, if one times her, one finds that she is producing more than the girl who appears to be working at breakneck speed, and who, in consequence of the effort expended in these vigorous strokes is compelled, either to take a complete rest, or to work quite slowly for a period in between these bursts of violent work. The principle, therefore, that was most impressed upon all girls under training was that printed at the foot of the instruction cards pinned on their benches, namely, "*Slow hard strokes are better than quick soft strokes.*"

The next point upon which emphasis was laid was the necessity for each individual worker to discover by experiment the number of strokes that were necessary for her to make on each portion of the spoon or fork. If this was in excess of the standard on the instruction card, she was told to try and exert more pressure, or in some way to alter her method of work until she could approach more closely to the standard strokes prescribed. The variations both in physical strength, height, and manual dexterity of each individual worker, naturally made it impossible to obtain absolute uniformity.

Finally, individual idiosyncrasies were examined and when these were found to be prejudicial to the worker, efforts were made to correct them. The following may perhaps be of interest in showing the types of difficulties that were found to exist.

There were three movements which were found to present difficulties to nearly all beginners. The first of these was the roughing of the front of the handles of the baguette pattern spoons when held in the right hand. To avoid removing the ridge down the centre of the front of the handle the spoons must be held first in one hand in order to rough one side of the ridge, and then in the other hand to rough the other side.

To do the work properly the wrist should be pushed well forward, flush with the edge of the wheel, and the spoons held parallel to the bench. No worker found any difficulty in doing this movement with the left hand, but when working with the right hand there was an almost universal tendency not to push the right wrist forward flush with the edge of the wheel, but instead to make a downward slanting stroke, with the result that only the left edge of the wheel, instead of the whole face of it, was brought in contact with the surface of the spoon. As a consequence, 10 or 12 strokes would often be required with the right hand, whereas five or six would be sufficient to attain the proper finish when working with the left hand. This difficulty is hard to explain satisfactorily, but most workers after constant reminders were able to overcome it.

A second rather curious difficulty very generally experienced was that of bringing the bottom spoon to the top after the completion of each portion of the spoon when holding four or six together. Most of the girls were observed to put the top spoon to the bottom instead of bringing the bottom one to the top, with the result that they were left with a hot spoon at the bottom against their hand, and frequently either burnt themselves or had to delay a little until the spoon cooled. The reason for this is probably that their attention being centred on the top spoon, their natural tendency is to complete, as it were, the operation by putting it to the bottom, instead of suddenly transferring their attention on to the spoon at the bottom of the pile. This difficulty like the other was usually overcome if the workers were reminded sufficiently often.

A third point that was particularly in evidence when roughing the back of the bowls, was the tendency to hold the spoons half way up the handle, instead of with the right fore-finger underneath the bottom of the bowl mouth, and with the right thumb resting along the back of the shank of the top spoon and pressed against the bowl. This holding of the spoons too far up the handle greatly diminished the pressure that the workers were able to bring to bear, and in consequence increased the number of their strokes, and reduced their speed. This fault was due to the fear of grazing the thumb against the wheel, but when it was demonstrated that owing to the curve in the bowl the wheel could not touch their thumbs, the workers quickly adopted the better method of holding the spoons.

The chief difficulties arising from the nature and shape of the ordinary plain spoons and forks, of the baguette, Windsor, and Old English patterns were encountered in the shoulders of both spoons and forks, and also along the edge of the prongs. The work of all beginners on these parts, especially on the edges of the prongs, requires considerable supervision, for the rougher is very liable by pressing too hard to wear down the tips of the outside prongs and so, by making them of uneven length, to ruin the fork. The Fiddle pattern, which is very generally manufactured, has difficulties peculiar to itself, but it was not encountered during the course of this investigation, and so no particulars can be given.

In addition to these difficulties which were encountered more or less universally, different girls had their own individual difficulties.

Before training, Worker No. 25 did practically no work with her arms, keeping her elbows close in to her side and swaying towards the wheel from her hips, so that the whole power of her stroke came from her body alone. As a result she was one of the slowest workers in the shop, and the quality of her work was very unsatisfactory. There was a risk that if her body swing was interfered with directly, and she were told to lessen it, her whole rhythm might be upset, and so effort was concentrated

upon getting her to do more work with her hands and arms, in the expectation that this would automatically reduce her tendency to sway. This plan was successful, and after a week's training she was able to reduce the time taken on three dozen dessert spoons from 154 minutes to 78, her body sway gradually disappeared, and her general methods of work became much more natural and less tiring.

This tendency of roughers to a pendulum-like swing of the body is a very noticeable feature of most buffing shops. In some shops almost every rougher seems to have adopted this method, and it is curious to watch them continue to sway when they have stopped work and are perhaps talking to a neighbour.

Another girl with this tendency very strongly developed was Worker No. 23. This worker had formed the habit of standing with her feet together rather far from the bench and then literally falling forward, bringing the whole weight of her body behind the stroke. The result was that she wore herself out long before the day's work was over, the speed of her work, even when she was fresh, was very slow, and she removed from three dozen dessert spoons 0·6 of an ounce (troy) more than any other worker, and 1 ounce more than the average worker. The first timing of her work was as follows :—

Time Taken.	Strokes Made.	Weight Removed.
148′	137	2·8 ozs.

At first it was hoped that by getting her to pay attention to the number of strokes made and to the proper use of her arms she would correct this plunging of the body. At the end of the week the results were :—

Time Taken.	Strokes Made.	Weight Removed.
113′	87	2·4 ozs.

Definite efforts were then made to teach her to control her body swing, by getting her to place one foot in front of the other and to pay special attention to her body movements. Considerable success was achieved in reducing her time and strokes, but the weight removed still remained at 2·4 ozs., thus showing that she was still tiring herself by doing unnecessary work. The results at this period were as follows :—

Time Taken.	Strokes Made.	Weight Removed.
89′	71	2·4 ozs.

For some time it seemed as though no further progress would be made, but about three weeks later, when her methods were again being studied, it was noticed that she had a habit of bringing up her work with a flourish between each stroke. This gave her the necessary space in which to make her downward plunge at the wheel. The suggestion was made that she should

lift the spoon no further from the wheel than was necessary for seeing the direction of the next stroke. She adapted herself to this immediately, and a marked decrease in body swing became apparent. Three days later she was again timed on dessert spoons with the following result :—

Time Taken.	Strokes Made.	Weight Removed.
84′	79	1·9 ozs.

As an instance of the type of minor difficulties that individual workers experience, the case of Worker No. 26 may be cited. This girl, when she first came for training, was unable to make a stroke straight up the back of the bowl. She had got into the habit of thrusting her right elbow out and so forcing herself to make a stroke diagonally across the bowl from right to left. To cure her of this habit was extremely difficult, and though she was persuaded to stand well to the left of the wheel, she still managed to stick her elbow out. However, after much perseverance, she was gradually taught to make the stroke in the proper manner, and after four or five weeks the tendency had disappeared altogether.

That it is the small details of position, &c., that often make all the difference between efficiency and inefficiency is well exemplified by the following instance :—One of the novices who came to learn roughing for a short time, but whose training had to be discontinued, was noticed to be standing too close to her wheel, as she had thrust the footstool upon which she was standing right up against the bottom of the bench, with the result that she forced herself into an awkward cramped position against the ledge that juts out from the top of the bench. She was timed when working in this way and took 14 minutes 45 seconds to rough four dessert spoons. She was then persuaded to move the footstool back about three inches, and was then timed again, doing four dessert spoons first in 10 minutes 30 seconds, and afterwards another four in 10 minutes 20 seconds. Too much emphasis cannot be laid upon the importance of attention to small details. The workers, as a whole, are very deficient in initiative, and they will continue to work in an uncomfortable position for weeks and months, realising dimly that they are uncomfortable, but never giving sufficient thought to the matter to discover the cause of their discomfort. In any training scheme, therefore, the first duty of an instructor is to discover anything that may be hindering a worker, and to have it removed or remedied.

The most common faults in the technical side of the process that need correction are connected with rosining. Many young workers have the idea that frequent application of rosin to the wheel is essential, whereas, as a general rule, it can be said that the better the worker the fewer times she has to rosin. A good worker with a buffing wheel in a satisfactory condition will probably have to rosin, at the most, only twice a day, but many young girls, if they are not carefully watched will rosin as often

as six times in a day, partly because it provides a pleasant interlude in the day's work, partly because from inexperience they do not apply their work squarely to the wheel and so wear it out round the edges of the leather, and partly because they do not realise that a small cut in the leather should be treated with soap and not rosin.

Not only does the junior worker rosin too often, but she also has a great tendency to put too much on at a time, and one can see the sides of their wheels with great masses of rosin crusted upon them. As much as $1\frac{1}{2}$ lbs. of rosin has been knocked off the sides of their buffs when they have been taken off the spindles. This, of course, is a great waste of rosin, but it also has the further disadvantage that it makes the buffing wheels untrue, and so creates vibration and increases the risk of cuts and grazes on the hands of the workers. All the rosin that is required is a thin film covering the whole surface of the leather. If more than this is put on, it is merely wasteful, for all the surplus rosin is cleaned off with a stick before work begins. Before the rosin is removed with a stick it should be allowed to cool for about five minutes, and the whole process should be completed in eight to ten minutes. This drying period is very useful, as it provides a natural rest pause for the worker, and it is of great importance that it should not be unduly curtailed. Much more time is wasted in applying unnecessarily large quantities of rosin than in allowing too long a period for it to cool.

Another point of some importance is the proper use of sand. This should be given ready mixed to the worker, as, if they are allowed to mix it for themselves, they will put in too much oil, with the result that after a very few days it will become sticky and unfit for use. The usual quantities laid down are one pint of buffing oil to 14 lbs. of sand, but after careful experimenting the sand was found to retain its cutting properties longer if it was mixed with oil in the following proportion :—21 lbs. sand, $1\frac{1}{4}$ pints of oil. The chief cause of stickiness of the sand is, however, the careless use of rosin. Before rosin is applied it is of great importance that the sand should be well covered with a piece of sacking or cloth, so that as little as possible of the rosin is mixed with the sand. Unless this is done, the sand after two or three days will lose all its abrasive properties and will form into sticky lumps. In this condition it is useless for roughing and smears the surface of the work instead of cutting it. Care should be taken therefore to ensure that the sand be kept free from rosin, and that it is immediately renewed when once it begins to lose its abrasive properties, otherwise great waste of energy will occur and consequent diminution of output.

Novices.

Four novices were trained in roughing, all of whom had asked specially to be trained. Their results varied largely with their

physical strength, but the Table shows the improvement effected in three weeks :—

Table XIII.—*Characteristics of Four Novices Roughing three dozen dessert spoons.*

Worker's No.	1st Week.		2nd Week.		3rd Week.	
	Time Taken. (min.)	Strokes Made.	Time Taken. (min.)	Strokes Made.	Time Taken. (min.)	Strokes Made.
27	138	135	126	97	$123\frac{3}{4}$	92
28	111	116	165	138	123	99
29	240	182	123	141	Absent, ill	
30	$138\frac{1}{2}$	121	90	109	81	82

Three of these four girls made considerable improvement but only one of them, No. 30, reached a standard sufficiently good to make further training unnecessary.

This girl was aged 17 whereas the others were aged 15 or 16, and she had had considerable experience as a colour dollier. The other girls had had practically no previous experience and were taken straight from their duties as messenger girls. The case of No. 28 who, after working very quickly in the first week, was much slower in the subsequent weeks, can be accounted for by the fact that at first she was sacrificing quality to speed. When this was checked, the standard of her work improved considerably, but there was a great slackening in speed.

Considering the results of this training scheme as a whole, they may be taken as satisfactory. From the limited experience gained with novices, roughing appears to be rather too difficult a task for a young girl. She should first be taught to dolly, and when she has grown accustomed to a wheel then she may be trained as a rougher with greater chances of success. This delay has a further advantage in that dollying is much less fatiguing work than roughing, and so more suited to a young girl. Observation on a small girl like No. 29 learning to rough, showed that the work was clearly beyond her strength, and that until she grew in height and strength she would never become an efficient rougher.

The training of girls with some previous experience was very successful. They all showed great keenness and the school was very popular in the shop, in fact after it had been running a few weeks several girls, whom it was not originally intended to train, asked whether they might be allowed to join.

So far as can be gathered there has never been in this trade a regular system of training in the past, the only experiment in this direction having been the Government's so-called training scheme instituted by the Ministry of Labour.

The Ministry naturally had to deal with conditions as it found them, and in the circumstances could not have acted otherwise than it did, but the results of this experiment are sufficient to suggest that the practical problem with which the Ministry was confronted would have been less difficult if investigations had previously been carried out with a view to determining the best methods of training. Some of the girls who participated in this experiment had been trained for a considerable period under the Ministry of Labour's scheme and yet were not sufficiently advanced to be put on piece-rate payment. A few weeks' training in this school soon brought them to a reasonable state of efficiency, so that they were able to take their place with the ordinary workers in the factory.

9.—GLAZING.

While this investigation was in progress the process of glazing was introduced into the factory with the object of assisting, if possible, the work of the rougher. Several spindles equipped with dust extractors were set apart for this purpose. Seats were provided and the roughers were allowed to glaze any of the work that they wished before roughing it.

The wheels used for this purpose were old outside grease dolly wheels, coated with a mixture of glue and 140 grade emery. They were not trimmed or in any way prepared before being given this coating, and so even when the glue and emery had been mixed in proper proportions and applied at the right temperature, the length of time the wheels lasted varied greatly.

When glazing was first introduced, the roughers were anxious to glaze both the edges and surfaces of the spoons and forks, but it was soon discovered that the glazing of the surfaces involved a considerable waste of time. In fact, the time taken to remove on a roughing wheel the scratches made on the surfaces by the glazing process proved to be almost as long as the time taken to remove the ordinary flaws and inequalities found on the surface of the metal before roughing.

The following timings served as the data on which this conclusion was based. These timings were frequently verified by observation of other workers and were found to hold good in all cases.

Worker No. 9. (*Table Forks*).	Total time for 1 doz. (min.)
Roughing throughout, 37½ mins.	37½
Glazing edges, 6 mins. Roughing, 25½ mins.	31½
Glazing edges and surfaces, 20¼ mins. Roughing, 16½ mins.	36¾

Worker No. 15. (*Table Spoons.*)

	Total time for 1 doz. (min.)
Roughing throughout, 31½ mins.	31½
Glazing edges, 6½ mins. Roughing, 22 mins.	28½
Glazing edges and surfaces, 12½ mins. Roughing, 20 mins.	32½

Worker No. 15. (*Tea Spoons.*)

	Total time for 1 doz. (min.)
Roughing throughout, 14⅓ mins.	14
Glazing edges, 2½ mins. Roughing, 10⅓ mins.	12

These figures indicated quite clearly that a saving in actual working time could be affected if the edges of spoons and forks were glazed after they had been filed, but, apart from the fact that the experiments only covered a short period, it was open to argument that the frequent changes from a roughing to a glazing spindle and back again would lead to an increase in time wasted, which would more than counter-balance the time saved in actual work. Against this theory it was argued, first that the change from a standing to a sitting position, afforded to each worker when she was glazing, would diminish her fatigue and so enable her to work more steadily, and secondly that since it is the rough edges of a spoon or fork that chiefly wear out the leather of a buffing wheel, the preliminary smoothing of these edges by glazing, would lead to an increase in the life of a buffing wheel, a decrease in the number of times that rosining would be necessary and consequently a decrease in the amount of time spent each day unproductively.

In order to get more satisfactory evidence on these points an experiment was carried out and for this purpose two girls, No. 15 and No. 23, were selected. Both these girls had been through the training school, but they represented two entirely different types of roughers. No. 15 was a fairly tall girl aged 17 with particularly long arms. She stood well up to her wheel and roughed in a singularly easy and rhythmic manner, making full use of her length of arm and getting the power for her stroke almost entirely from her arms. No. 23 was a growing girl aged 16, of average height, whose strength was as yet undeveloped. She was, however, a tremendously heavy worker and by a violent swaying motion brought the whole weight of her body behind each stroke.

Observation on each of these workers extending over two days was then made. During the first day, each girl was given table spoons and told to rough them without glazing, and on the second day she was again given table spoons but told to

glaze their edges before roughing them. During each of these two days, the girl undergoing the experiment was observed continuously and her output, rest pauses, rosining periods and periods spent on unproductive labour, were carefully noted.

During her first day's experiment, that is, when she was roughing the spoons throughout, Worker No. 15 completed 10 dozen and 4 spoons. Table XIV. gives the actual times taken, excluding all periods when she was away from her spindle, either for rosining, rest, fetching fresh work, or for other reasons :—

Table XIV.—*Output of Worker* 15 (*Roughing only*).

Spoons.	Rate of work (min. per 3 doz.).	Hour Completed.
1st 3 doz. - - - - -	100½	10.47 a.m.
2nd 3 doz. - - - - -	119½	2.3 p.m.
3rd 3 doz. - - - - -	98½	4.19 p.m.
Last 16 - - - - -	120½	5.25 p.m.
124	*108*	——

On the 2nd day, when she was glazing the edges of the spoons before roughing them, her output was 11 dozen, and her times, excluding all periods when she was away from her spindle were as follows :—

Table XV.—*Output of Worker* 15 (*Glazing and Roughing*).

Spoons.	Rate of work (min. per 3 doz.).			Hour Completed.
	Glazing.	Roughing.	Total.	
First 20 - -	32½	77½	110	9.17 a.m.
1st 3 dozen -	20	80	100	11.31 a.m.
2nd 3 dozen -	29	77	106	2.43 p.m.
3rd 3 dozen -	33	85½	118½	5.9½ p.m.
Last 4 - -	—	—	—	—
132	*28*	*80½*	*108½*	——

(A description of the training of this girl has been given in the section on the training of roughers. It was at the end of the second day of this experiment that she was persuaded to keep her work closer to the wheel between each stroke, thus curtailing her body swing.)

The output of Worker No.23 under exactly the same conditions was on the first day 9 dozen and 4. The time taken and the hours at which she completed each 3 dozen spoons were as follows :—

Table XVI.—*Output of Worker 23 (Roughing only).*

Spoons.	Rate of work (min. per 3 doz.)	Hour Completed.
1st 3 dozen - - - - -	107	10.17 a.m.
2nd 3 dozen - - - - -	114	1.50 p.m.
3rd 3 dozen - - - - -	137	5.5 p.m.
Last 4 - - - - - -	—	—
112	*119*	——

On the 2nd day, when the edges of the spoons were glazed before being roughed, the output of Worker No. 23 was 9 dozen, and excluding as before all rest periods and periods of unproductive labour her times were as under :—

Table XVII.—*Output of Worker 23 (Glazing and Roughing).*

Spoons.	Rate of work (min. per 3 doz.).			Hour of Completion.
	Glazing.	Roughing.	Total.	
First 32 - -	$33\frac{3}{4}$	$86\frac{1}{2}$	$120\frac{1}{4}'$	10.31 a.m.
1st 3 dozen -	25	$114\frac{1}{2}$	$139\frac{1}{2}'$	2.14 p.m.
2nd 3 dozen -	27	$116\frac{1}{2}$	$143\frac{1}{2}'$	5.19 p.m.
Last 4 - -	—	—		—
108	*$28\frac{1}{2}$*	*104*	*135*	——

The results show that on the second day when the edges were glazed, the output of Worker No. 15 increased by 8 spoons, whilst that of Worker No. 23 decreased by 4 spoons on the second day. In both cases, however, the output on the second day would have been considerably larger had the glazing wheels been in a more satisfactory condition; unfortunately they had been prepared by a young girl new to the work who had mixed too small a quantity of emery with the glue, with the result that the wheels wore out very quickly, and, for each three dozen spoons, had to be changed two or three times, much delay being thus caused.

Norwithstanding the difficulties experienced with the glazing wheels, certain deductions may be drawn from the figures obtained in this experiment.

Glazing is a process which demands little expenditure of energy on the part of the worker and it may safely be assumed that

variations in the time taken by the same girl to glaze a given task will depend chiefly upon the wearing qualities of the glazing wheel.

In *glazing*, the figures show that there was no consistent tendency for the rate of work to diminish as the day progressed. The minimum time required to glaze 3 dozen table spoons was 20 minutes by No. 15, and 25 minutes by No. 23. In neither case were these minima attained early in the morning; they were due so far as could be seen entirely to the fact that the girls were using a good abrasive wheel, and so they can be considered as their normal times.

On the other hand, on all four days the time taken to *rough* three dozen spoons increased towards the end of the day, indicating thereby the presence of fatigue. This was fully borne out by the investigator's own observations of the girls at work, for each in her own way showed ever increasing signs of fatigue as the day wore on.

In Worker No. 15 these signs were displayed by frequent movement of the feet and stretching of the muscles of the legs. She also sought some relief from the monotony of the work by collecting the sand out of her apron more frequently and by making longer pauses than before for this purpose. The most noticeable feature of the increase of fatigue in Worker No. 23 was the marked decrease in her powers of concentration. At the beginning of each day she applied herself vigorously to her work, but quite soon her attention began to wander and by the end of the day the slightest noise or incident was sufficient to distract her attention for several minutes at a time. She is naturally of a somewhat effervescent and excitable disposition. For this reason the records of her work are not so reliable as the records of a steady worker like No. 15.

Worker No. 23 undoubtedly tired herself by her violent methods of work, and by the early afternoon in each day showed unmistakable signs of fatigue, both when she was roughing the spoons without previously glazing them, and when she was roughing them after glazing. Since her fatigue was chiefly marked by a lack of mental concentration and by a readiness to be distracted by the conversation of her companions, and by any unusual sight or sound in the factory, it follows that her output was in some degree controlled by the frequency and duration of these external causes of distraction and not only by the intensity of her own fatigue. From the figures it will be seen that on each of these days the time she took to rough the last 3 dozen spoons in the afternoon was 30 minutes longer than the time she took for the first 3 dozen in the morning, and so no lessening of fatigue is apparent from the introduction of glazing. As pointed out above, this can be accounted for by the somewhat unstable disposition of this worker and it is almost impossible to assess by observation the time lost by a girl who

while continuing her work is at the same time talking and laughing with her friends. She herself stated that she found glazing a considerable help to her, and that the occasional periods of sitting rested her feet and made her less tired at the end of the day, but as there are no figures to prove this, the question must be left open.

The figures of Worker No. 15 show a considerable improvement on the second day when glazing was introduced. On the first day when she roughed the spoons without glazing them, her time for the last 3 dozen was 20 minutes slower than for the first 3 dozen. On the second day after glazing the edges she took only 8 minutes longer at night than she did in the morning, and the fluctuations in the time taken to complete each 3 dozen spoons were very small. This girl was a particularly steady worker and her work was very little affected by her external surroundings.

The time spent away from their wheels was also calculated. On the first day Worker No. 15, when roughing without previously glazing the spoons, spent 61½ minutes unproductively, and of these 61½ minutes, 51 were spent either in actually applying rosin to the wheel or in waiting while the rosin cooled. On the second day when roughing after having first glazed the edges, she spent 52 minutes unproductively, of which 22 minutes were spent in rosining, and only 9 minutes in changing from the glazing to the roughing wheel. Glazing had then the effect of decreasing her unproductive labour by 9½ minutes, and whereas on the first day she had to rosin 4 times, on the second day, twice was found to be sufficient.

Worker No. 23 on the first day spent 88½ minutes unproductively, and of these 77½ were spent either rosining or away from the factory while the rosin was cooling. On the second day her total unproductive labour amounted to 55 minutes, and of these 33 were spent rosining, and only 4 in changing from the glazing to the roughing wheel. In this case, therefore, there was a decrease of 33½ minutes in time spent unproductively on the day when she glazed her work, and instead of rosining six times as she did on the first day, she only rosined three times.

From these observations on the introduction of a preliminary glazing process to remove the file marks on the edges, the following conclusions can be drawn :—

1. Careful attention should be paid to the proper preparation of the glazing wheel. If good wheels are provided a considerable saving of time is possible, but if not, the time wasted in working with a wheel covered with a poor abrasive and in continually changing the glazing wheels will more than counter-balance the time saved in roughing.

2. There is a strong probability that the introduction of glazing diminishes the fatigue of the worker, by enabling her to sit at her work for certain periods during the day. Owing

to the peculiar characteristics of worker No. 23, the evidence as to this is not quite conclusive, but the figures of the steady worker No. 15 fully bear out this assumption.

3. Glazing decreases the amount of rosining necessary, and so effects a saving in time spent unproductively. The time wasted in changing from the glazing wheel to the roughing wheel only amounts to 9 minutes during the day—in one case and 4 minutes in the other.

4. Since rosin is only applied when the buff is beginning to wear, a decrease in the number of times that rosining is necessary implies less wear upon the buffs, and so there is a saving in working costs through the increased life of the buffs.

10.—EXPERIMENT WITH A WATTMETER ON THE PROCESS OF ROUGHING.

The following experiment was made possible by the kindness and generosity of Mr. Julius Frith, M.Sc., M.I.E.E., M.Cons.E., of Manchester who lent a recording wattmeter for the purpose. This instrument gives a continuous graphic record of the amount of electrical energy expended by the motor in use. The line given on the chart representing the energy expended by the motor in revolving the buffing wheel when no roughing operation is in progress, will be known as the zero line.

In the roughing process the thrusting of the article against the wheel results in a frictional retardation of the buffing wheel, and the amount of energy expended by the motor to overcome this friction is accurately marked upon the chart. Moreover from the nature of the process this friction cannot be caused passively, the girl cannot lean the spoon against the wheel and so the amount of friction caused is directly dependent upon the human effort exerted. Hence the height of the individual strokes above the zero line made by the pen of the wattmeter on the chart can be assumed to correspond to the amount of effort put forth by the rougher.

Since the wattmeter records every stroke of the rougher against the wheel, and also every pause between the strokes, a graph is automatically obtained giving a complete time study of the operation under investigation. Arrangements were made to have this instrument connected with a spindle that had been detached from the shafting driven by the main factory motor. The work of any girl sent to this spindle could thus be isolated and a complete chart of her work during any given period obtained.

For this experiment, two roughers, workers No. 15 and 23 employing very different methods were selected. No. 15 was a very steady worker and was noticeable for the easy rhythmic

manner in which she roughed. No. 23 was of an excitable temperament and an unsteady worker. Her methods of roughing were characterised by a violent swaying motion of the body culminating in a heavy thrust of the spoon against the roughing wheel.*

Each girl was set to work in turn at the spindle driven by the motor to which the wattmeter had been attached and was observed at her work for two days, during which she was kept supplied with table spoons.

Owing to the great difficulty of reading a chart which records each movement of the worker, no attempt was made to obtain a continuous chart of the whole day's work, but the experiment was confined to getting complete records of the roughing of four spoons at various intervals throughout the day. The following were approximately the hours at which records were obtained :—

8.45 a.m.—This allowed the girl time to "get into her swing." Work having started at 8.0 a.m.
9 45 a.m.—*i.e.*, Just before the morning break at 10.0.
10.45 a.m.—*i.e.*, After morning break, allowing the girl time again to get into her swing.
12.15 p.m.—*i.e.*, Just before dinner hour and, therefore, likely to show evidence of morning fatigue.
2.15 p.m.—*i.e.*, After dinner hour. Again allowing time for girl to get into her swing.
3.15 p.m.—*i.e.*, Just before tea.
4.15 p.m —*i.e.*, After tea allowing time to get into her swing
5.15 p.m.—*i.e.*, Just before work finished at 5.30. Likely to show evidence of the total day's fatigue.

During the first day with Worker No. 15 a record was obtained at each of these hours except at 10.45 when, owing to a slight mischance with the wattmeter no record could be taken.

At 3.15 p.m. on this day an exceptionally fast time was obtained. This was accounted for by the fact that just before the record was taken, No. 15 asked the investigator whether she was working satisfactorily and the object of the experiment. He told her, and the result was a great stimulation in her interest resulting in much quicker work. This additional stimulus soon wore off and at 5.15 the curve was again normal.

During the second day of Worker No. 15 and the first day of Worker No. 23, the full eight records were obtained in each case. Unfortunately on the second day of Worker No. 23 the instrument broke after two records had been obtained and the experiment with the wattmeter had to be abandoned.

In analysing these records detailed examination was confined to the roughing of the backs of the bowls. This particular portion of the spoons was selected, first because the surface is large and the roughing of it is therefore likely to give evidence of any fatigue that may exist, secondly because long heavy strokes are generally applied in roughing it, and thirdly because the work is not complicated by any difficult corners or pattern.

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* For further description of these two workers see § 9 *Glazing.*

The following method was adopted in examining these charts. First the total time taken to rough the four bowls and the average time per bowl was ascertained from the wattmeter records. The number of strokes per spoon counted and each stroke measured, and in this way the average length per stroke in centimeters on each record was obtained. Finally the time taken on each four bowls was divided by the total number of strokes, thus giving the average duration of each stroke.

The results are given in Table XVIII., which brings out in a most striking fashion the great difference in the methods of

Table XVIII.—*Wattmeter Analysis of Movements of Two Workers.*

Hour of Records.	Total time for 4 Bowls. (Sec.)	Average time per Bowl. (Sec)	Total duration of pauses. (Sec.)	Average no. of strokes per Bowl.	Average pressure of each stroke.* (Cm.)	Average duration of each stroke. (Sec.)
	Worker No. 15. First Day.					
8.45 a.m. -	52·8	11·4	7·2	17¼	2·50	0·65
9.45 a.m. -	78	18	6	17	2·09	1·06
10.45 a.m. -						
12.15 p.m. -	77	17·1	8·6	17¼	2·73	0·99
2.15 p.m. -	78 2	16·9	8·6	16½	2·14	1·02
3.15 p.m. -	57	12·9	5·4	14¾	2·41	0·87
4.15 p.m. -	76 6	15	16·6	16	2·27	0·94
5.15 p.m. -	101·2	23·6	6·8	22½	2·27	1·05
	Worker No. 15. Second Day					
8.45 a.m. -	66	15·2	5·2	16½	2·21	0·92
9.45 a.m. -	51	11·2	6·4	15½	2 61	0·72
10.45 a.m. -	79	15·5	17	16	2·30	0·97
12.15 p.m. -	76	16·8	8·8	16½	2·30	1·02
2.15 p m. -	83	19·5	5	18¼	1·99	1·07
3.15 p.m. -	74	15·5	12	15¼	2·52	1·02
4.15 p.m. -	84	19·2	7·2	17¼	2·44	1·11
5.15 p.m. -	101	18·2	28·2	16¼	2·63	1·18
	Worker No. 23.					
8.45 a.m. -	89	19	13	15	2·62	1·27
9.45 a.m. -	98	22·2	9·2	16½	2·76	1·35
10.45 a.m. -	103	21	19	15¾	3·02	1·33
12.15 p.m. -	107	21·6	20·6	14¼	2·89	1·52
2.15 p.m. -	115	26	11	17¾	2·81	1·47
3.15 p.m. -	118	25	18	16½	2·65	1·52
4.15 p.m. -	119	27	11	16¾	3·64	1·61
5.15 p.m. -	139	31	15	16	3·24	1·94

work of these two girls, and the large amount of extra energy that No. 23 puts forth. This additional pressure resulted, as

* As indicated by height of curve on Wattmeter record.

has been shown in the report upon roughing, in her removing from 2·4 to 2·8 oz. (troy) of metal from 3 dozen dessert spoons, whereas No. 15 removed on an average slightly less than 1·8 oz. The work turned out by No. 15 was, however, of excellent quality, and the additional pressure exerted by No. 23 was wasted labour and had the effect of unnecessarily fatiguing her and at the same time wearing out the roughing wheel.

A detailed examination of these tables shows that in all instances the time taken to rough four bowls increases towards the end of the day. In the case of No. 15, this increase was gradual and fluctuating, but in the case of No. 23 it was much greater, and is continuous throughout the day. The number of strokes made by each worker was about the same and showed only a slight tendency to increase towards the end of the day. The height of each stroke above the zero line, which is a comparative measure of the pressure exerted in each stroke, showed a marked tendency to increase during the afternoon, but here again this was much more evident in No. 23 than in No. 15. The duration of the stroke also increased during the day in all cases, and the increase was especially marked during the work period in the late afternoon. It is evident from this, that both these workers, but especially No. 23, as they grew tired towards the end of the day were inclined to give more vigorous strokes and to take longer over each individual stroke.

Two factors are present which together determine the duration of the stroke, namely, the length of time that the pressure of the spoon against the wheel is sustained and the length of the pause between successive applications of this pressure.

An examination of the charts shows quite clearly that both these factors were in operation, and that towards the end of the day's work both girls made more sustained strokes and also paused for a longer time between each stroke.

Another method of measuring the wattmeter records was suggested and kindly carried out by Mr. Frith. A planimeter was used for measuring the areas enclosed by the recording pen of the wattmeter. These measurements give the energy expended by the motor in order to overcome the frictional retardation caused by the worker pressing the spoon against the revolving wheel and so give an approximate measure of the human effort exerted. The areas averaged throughout the day are—

Worker 23, 2·8 sq. in.
,, 15, 1·1 ,,

for the roughing of the bowls of four spoons.

The detailed results of Mr. Frith's measurements together with his explanatory notes are given in Table XIX.

Table XIX.—*Wattmeter Analysis of Effort expended by Two Workers.*

1. Approx. time of Day.	2. Chart area per 4 Bowls. (Sq. in.)	3. No. of strokes N (4 Bowls).	4. Average duration (W + R) (Secs.)	5. N(W + R) (Secs.)	6. Total Time per 4 Bowls. (Secs.)
		Worker No. 23.			
8.45 a.m. -	2·0	60	1·30	78	89
9.45 a.m. -	2·1	66	1·36	90	98
10.45 a.m. -	2·9	63	1·46	92	103
12.15 p.m. -	2·5	57	1·37	78	107
2.15 p.m. -	2·9	71	1·36	97	115
3.15 p.m. -	2·7	66	1·31	87	118
4.15 p.m. -	3·9	67	1·49	100	119
5.15 p.m. -	3·7	64	1·67	107	139
		Worker No. 15.	*Second Day.*		
8.45 a.m. -	1·0	60	(Charts)	(undecipherable)	66
9.45 a.m. -	0·7	57			51
10.45 a.m. -	1·0	64			79
12.15 p.m. -	1·2	66			76
2.15 p.m. -	1·1	73			83
3.15 p.m. -	0·8	61			74
4.15 p.m. -	1·3	69			84
5.15 p.m. -	1·1	65			101

Explanation of Table.

Column.

1. Time of day at which readings were taken.
2. Area of wattmeter chart (above 150 line), for work on four bowls. The 150 line was taken as indicating the electrical energy absorbed by motor and machinery running light.
3. The number (N) of *strokes* (*see* below) in completing four bowls.
4. A *stroke* includes two periods :—

   W. seconds, in which the spoon is held against the buff.

   R. seconds, rest or pause before the next stroke.

   The average lengths of W. and R. were measured from the charts by means of a micro-scale. They were measured along the 190 line, which was chosen arbitrarily for this purpose.

   Column 4 gives the *sum* of average W. and R. or time of a complete stroke.
5. N. multiplied by (W. plus R.) or the time occupied by all the strokes.
6. The over-all time of the operation on four bowls, as recorded by the clock.

It is unfortunate that the records obtained from Worker No. 15 were so blurred that they did not lend themselves readily to measurement by means of the planimeter.

The correlations between Mr. Frith's planimeter measurements of effort exerted and the results obtained by the method previously described are as follows :—

In the case of Worker No. 23 r = +·86
,, ,, No. 15 r = −·51

The minus correlation in the case of Worker No. 15 coupled with the fact that the graph on the wattmeter chart was very blurred seems to suggest that the first method adopted namely that of measuring the height of each strok in this case likely to be more satisfactory than measurem area by a planimeter.

A large margin of error must be owed in measuring exactly such minute records as those supplied by the wattmeter.* This factor of human error which must necessarily enter into the work need not materially affect any theory which is based upon the records, since any such theory must depend on a comparison between measurements in the same series in which the factor of error may be taken as constant.

In a previous part of this report it has been shown that fewness of strokes corresponds very closely with high output. The natural inference, therefore, was that in getting maximum output, the fewness of the strokes must be compensated for by a greater pressure exerted in each stroke or by an increase in the time during which the article is held against the wheel.

Putting this another way, and using the terminology employed in the charts, fewness of strokes implies increased duration and increased pressure, if good output is to be maintained. When, however, the curves were plotted as in Fig. 3, a marked

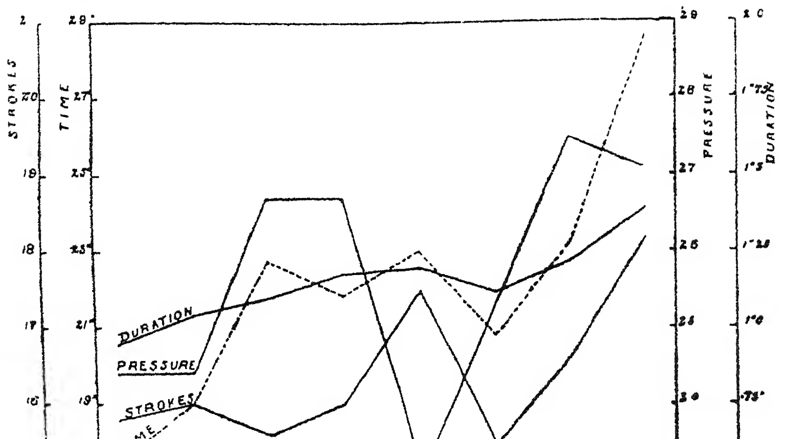


Fig. 3.—Duration, Pressure and Strokes in Roughing Four Table Spoons compared with Time required.

correspondence is found between shortness of time to perform the operation, fewness of strokes, shortness of duration, and

* *See* Photographs, Appendix II.

lightness of pressure, which if there were no limiting factors, would result in an obvious absurdity. Fig. 3 shows that the curves representing strokes, duration and pressure follow the line of output fairly closely in the morning. The correspondence is still noticeable in the afternoon, though the variations are more marked.

The accounts of earlier experiments carried out in time and motion study have described the large part played by rhythm in the easy performance of most industrial operations and probably rhythm is the determining factor in this case too. In the earlier part of the day when the worker is fresh, the work is done rhythmically and the results are satisfactory. The nearest approach that can be made to instil rhythm is by modifying the number of strokes. It will be seen that the number of strokes per spoon varies little in the morning and that greater variations are introduced in the afternoon, as fatigue increases the natural rhythm of the body seems to break down and conscious effort is invoked in order to do the work.

This is shown by the increased effort put into the work, as indicated by increased pressure, duration and number of strokes, but in spite of this effort, or perhaps on account of it, the time required to perform the operation steadily increases. The natural rhythm of the worker seems to have been broken by fatigue, and in order to counteract this, the more complicated and lengthy mental processes of volition and conscious effort have been introduced with their natural fatiguing effect.

The fact that this curve tends to rise as the time to perform the operation rises, seems to show that as the worker becomes fatigued the co-ordination between the factors represented by the curve of rhythm becomes more and more disturbed, fatigue having the effect not only of slowing the re-action times as shown in the curve representing duration of strokes, but also causing a certain lack of motor control resulting in increased pressure and increased number of strokes. The tired worker is, therefore, not only working slower than when she is fresh, but is also expending her energy extravagantly. If this interpretation is right, it would imply that in order to obtain a satisfactory output throughout the day an attempt must be made to retain the even rhythm shown by the workers in the morning, so as to prevent the excess of effort put forth during the afternoon. Attention must be paid not to an external standard that the worker must attain, but to the internal mechanism of the nervous and muscular systems.

A parallel will be found in the case of a rowing crew. When the crew is fresh and well trained the boat swings along with a natural rhythm which is the result of the combined rhythm of the oarsmen. When the crew is tired, there is a tendency for the rowing to become "ragged," which means that the rhythm has been broken. The method of reviving a "ragged" crew is not

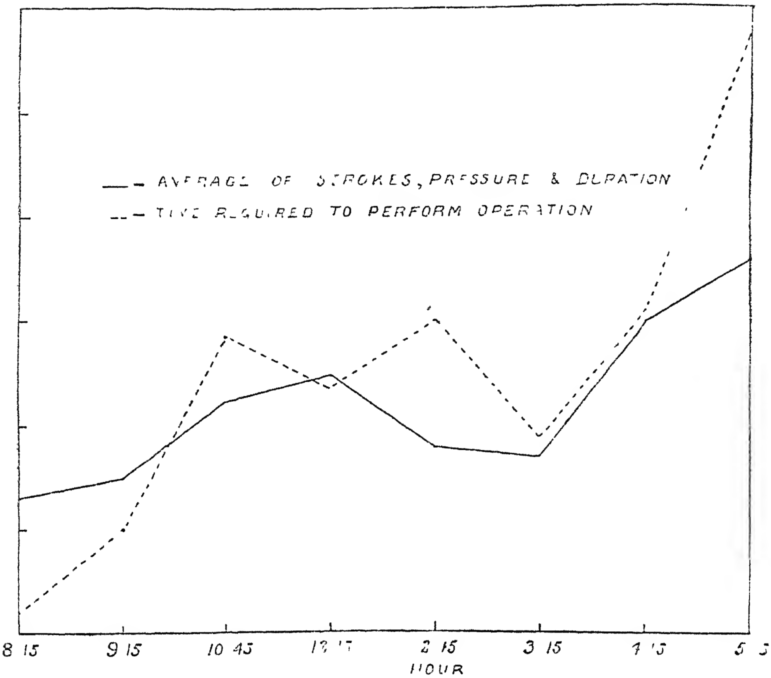


FIG. 4.—AVERAGE OF DURATION, PRESSURE AND STROKES COMPARED WITH TIME REQUIRED.

to get them to put more effort into their rowing, but to encourage them to " smarten it up " which means getting back the feeling of rhythm which has been lost.

If the suggestion put forward is correct, it follows that in order to increase the efficiency of certain industrial operations, attention must be paid not to speed, nor even to the elimination of unnecessary movements as an end in itself. The first thing to do is to devise and give proper instructions in a rhythmic method of doing the work. In an earlier part of this report an account is given of a system of training which had as its object the reduction of the number of strokes employed. The wattmeter records show that fewness of strokes, and small variation in the number of strokes for the same operation, are always found when the work is based upon the natural rhythm of the worker, and that the opposite is the case where this rhythm breaks up and is replaced by conscious effort. It may therefore be assumed that the best way of teaching a rhythmic method of working is by means of limiting the number of strokes.

The next task is to endeavour to devise some method whereby this natural rhythm may be continued as long as possible and not be broken up by the onset of fatigue.

The experiment dealing with rest pauses may indicate a method of retaining this felt rhythm for as long as possible.

Fig. 5, giving a comparison between the two workers experimented upon, shows how much more effort No. 23 puts into

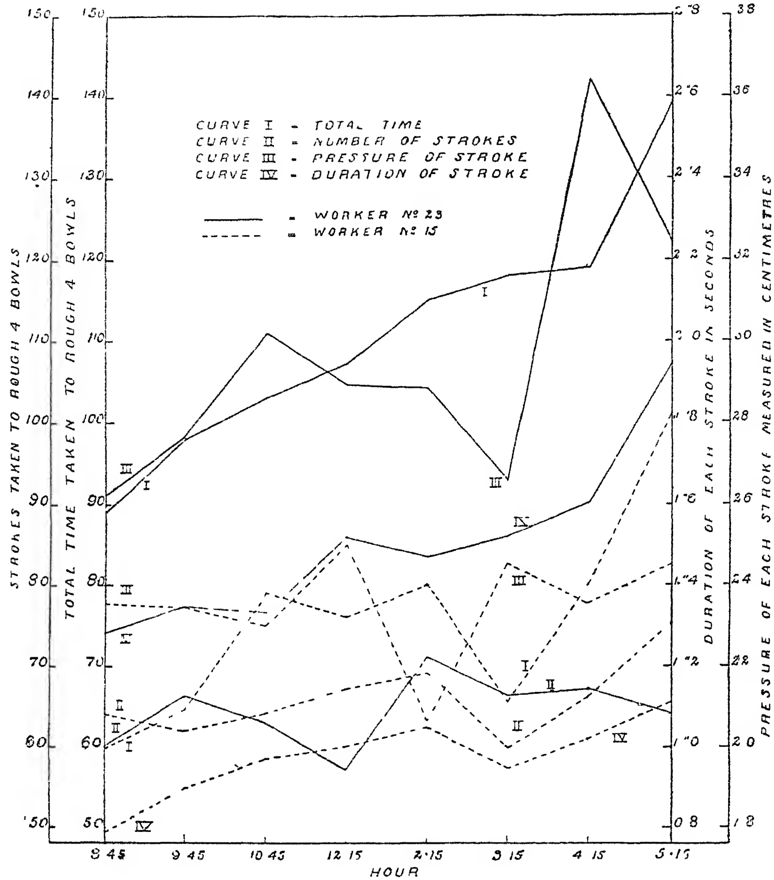


FIG. 5.—PERFORMANCES OF WORKERS 23 AND 15 COMPARED.

her work as compared with No. 15, with the result that her output is considerably less throughout the day. The number of strokes employed by each worker vary little, but the pressure and duration of each stroke employed by No. 23 is greater throughout the day, and it has already been shown that she removes more metal from the article than is necessary.

This would indicate that there are other factors besides the lack of rhythm which make for fatigue. There is a well known dictum in golf that you must keep your muscles quite slack in order to get the natural swing, which is essential for a really effective stroke. The stroke may be perfect when regarded only from the line the head of the club describes through the air, but if there is a tendency to press, *i.e.*, put too much effort into the stroke, the result will not be good. Something similar to the fault of "pressing" at golf seems to be present in the case

of Worker No. 23. Too much effort is put into her work, with the result that the time she takes to perform the operation in question steadily increases throughout the day, and there is never any recovery. With No. 15, the increases in time is not so rapid and two recoveries are made during the day.

11.—AN EXPERIMENT IN REST PAUSES.

The object of this experiment was to discover the relation between the work done and the rest taken. To obtain reliable information on this subject, obviously a steady worker who was interested in her work and endeavoured to do it as well as possible was required for purposes of experiment. Observations were made in a rougher 21 years of age who was strong and healthy. The evenness of her day's work was very marked. When distractions occurred in the shop which caused other workers to leave off their work, this girl continued quite undisturbed. It may therefore be assumed that the rest pauses taken by her were made necessary by the fatigue she felt and were not due to extraneous factors.

Accurate timings of her work were taken for periods of three days, first when she was working normally and taking such rest as she thought fit and at such times of the day as she pleased, and afterwards when rest pauses of five minutes in each hour were organised and put at regular intervals during the day. During the former period the average time required to rough a dozen dessert spoons was 32 minutes 30 seconds, and during the latter 31 minutes 20 seconds. In Fig. 6 a comparison of the two periods can be seen. The curve representing the three days' work with unorganised rest pauses, varies far more than the one representing the three days' work in which there were organised rest pauses. This seems to indicate that the onset of fatigue is checked by the introduction of rest pauses, and if this is so we

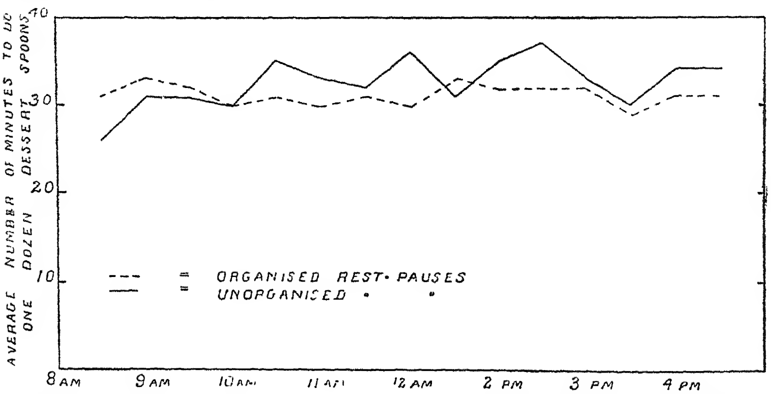


FIG. 6.—TIME REQUIRED TO ROUGH ONE DOZEN DESSERT SPOONS WITH ORGANISED AND UNORGANISED REST PAUSES.

may assume that rhythm is allowed to play a larger part in the work.

In order to test this, further experiments will have to be carried out in conjunction with the wattmeter, but the results of these two separate experiments at least seem to indicate a fruitful field of research.

12.—AN EXPERIMENT IN INSIDING.

Insiding of table spoons is done with a buff not more than 3 inches in diameter. Hence, if the spindle is driven at the same speed as the spindles for the roughing wheels, with a diameter 12 inches, the peripheral speed of the buff is much less than that of the larger wheels.

Experiments were made with two workers, A and B, working on buffs revolving at various speeds. The results were as follows :—

Table XX.—*Effect on Output in Roughing of Speed of Wheel.*

Worker.	Time (in seconds) required to inside 1 doz. table spoons.		
	2252 r.p.m.	2892 r.p.m.	3230 r.p.m.
A - - -	422	379	411
B - - -	455	393	430

It was impossible to carry out more extended experiments, which would be necessary if the most effective method of insiding is to be determined. As the speed of the buff increases, the amount of human effort required becomes less, but the danger of slipping off the buffs and grazing one's fingers becomes greater. A proper adjustment between these two factors will determine the proper speed for an insiding wheel.

An account of this experiment has been given, not because the present results are thought to be valuable, but because they indicate what is at present an almost untouched field of experiment.

13.—SUMMARY.

1. By close observation of the movements of a number of emery wheel filers, provided with seating, glass screens and contoured rests, the unproductive time was considerably reduced. Then by training, and the institution of a team in the case of "set" forks, the output in two shops increased without any apparent increase of effort on the part of the workers.

2. The design and provision of seats for outside dolliers were arrived at after a close study of an individual worker on a wide variety of work over 6-day periods, standing and seated. The effects of seating resulted in greater buoyancy in the workers, and the output seated is slightly higher than with continuous standing. The greater comfort of voluntary continuous or intermittent seating was appreciated by all the workers.

3. The methods of work and movements of a number of outside grease dolliers were systematically observed. Astonishing differences were noticed between workers with long years of experience. Eventually a systematised set of movements was employed in a training scheme which resulted in great improvement in the work and piece-work earning of many of the older hands. This training with novices in a few days enabled a standard efficiency to be attained hitherto said to be attained only after months of practice.

4. A similar study of the movements in roughing had also satisfactory results when applied to a training scheme, although in this process a longer time is required to attain proficiency on account of the more complicated movements. The attempt to reduce the number of strokes, to do more work with the hands and less movement with the body, quickly leads to a more rhythmic use of human energy with increased comfort to the individual and improved quality of the work.

5. The process of glazing on wheels dressed with emery was under observation, and although the material side of the question is somewhat outside the scope of this investigation, the change of practice, by relieving some of the more strenuous work of roughing, gives a noticeable relief to the worker and considerably reduces the rosinning required to keep the roughing wheels in condition. This glazing of the edges of spoons and forks is of special interest, as it is one of the chief differences between French and English practice.

6. A recording wattmeter connected with a separate motor driving an individual wheel enabled a graphical illustration of every separate movement, and an approximate estimate of its duration and strength, to be obtained. These records for the moment have been specially directed to observing the incidence of fatigue at different periods of the day's work.

7. Since in actual practice no worker can continuously perform any operations of the nature of polishing throughout a working day without suitable rest pauses, an attempt was made to study the effect of artificially introducing regular pauses each hour, and comparing the time thus allowed and the effect on the work with the time voluntarily taken by a steady worker.

8. Attention is drawn to some preliminary results obtained by running an insiding buff at different speeds.

14.—CONCLUSIONS.

1. A definite course of training should be given to all workers who enter the buffing trade, instead of allowing them to pick up their trade as best they can. The present method is wasteful of human energy and is to the advantage of neither the employer nor the employed.

2. This course of training should be based on the principles indicated in this report. No claim is made that they represent a final stage of perfection, but only that they are more satisfactory than the traditional methods.

3. Further experiments should be carried out in the buffing trade. Among the problems which require research is that of vibration. An attempt was made to deal with this problem in the course of the experiments described in this report, but no conclusions could be arrived at. The connection between rhythm, fatigue and rest pauses should be more carefully examined.

4. Efforts should be made on the technical side to devise an abrasive which is less dusty and dirty than loose sand; and not so coarse as an emery wheel. If sand were replaced by a less objectionable abrasive, the roughers would be saved much discomfort.

5. Seats should be provided for the workers and their benches should be modified in such a way as to permit the use of the seats without discomfort being caused by inadequate space for the legs.

6. Further research should be carried out on the proper size and breadth of wheels and the most economical speed at which they should revolve.

APPENDIX I.

VISIT TO A FRENCH SPOON AND FORK FACTORY.

Information having been received that the methods employed in France in polishing spoons and forks differed considerably from those usual in this country, arrangements were made to visit a French factory where these processes are carried on.*

Marked differences were, indeed, found to exist in practice. For instance, processes in this country on which women are employed are carried out in France by men, and *vice versâ*; the sub-division of the work is carried much further, and the output per individual employed is much greater. On the other hand, owing to the fact that a more decorated article is manufactured to a larger extent, the high polish, characteristic of English work, is not required. One point of special note is that the work is carried out up to the point of final "colouring" by identical methods and to the same standard, whether the article is to be plated or not.

Roughly speaking, the French practice is divided into three stages:—(1) Emery Wheel Filing; (2) Glazing (*adoucissement*); (3) Polishing. It is interesting to note that as there is a wide variety of patterns and articles the system of payment is fixed by varying the number of articles of every size and pattern to a standard "livraison" or "tâche," *e.g.*, in polishing, the "*tâche*" may comprise 128 plain baguette tea spoons, 90 baguette table spoons, down to 63 table spoons of a very fancy pattern.

Inspection.—Undoubtedly the work of polishing is greatly assisted by the highly organised system of inspection. The blanks before the final rolling or stamping process are looked over, wasters are rejected and minor surface defects corrected by glazing or emery wheel grinding. Further inspections are arranged after the "*adoucissement*" and after the polishing. It was stated that in this factory, on the average, to obtain 1,000 perfect spoons, 1,300 blanks are cut out before final rolling, 1,110 are given out to the emery filers, and 1,070 are passed to the polishers.

Emery Wheel Filing.—The work is more sub-divided than is usual in this country. For instance, with table forks, the following sequence was noted, the blanks being flat. (Emery wheels are all provided with large glass screens):—

(*a*) Edging of handle and shank.
(*b*) Sides of prongs.
(*c*) Pronging on thin emery wheel.
(*d*) Smoothing inside of prongs on a thin circular steel file.
(*e*) Pointing in on ½-inch emery wheel grooved on its periphery.

Glazing.—This work is considered very important, as all articles must have smooth edges before passing to the polishers. Indeed, the polishers themselves, as will be seen, always begin by re-glazing the edges with a finer grade of emery. As an example, with the table forks, the following stages were observed:—

(*a*) Between the prongs with three thin leather discs clamped together, the sides of the discs being coated with glue and emery (140).
(*b*) Edges of shanks.
(*c*) Sides of outer prongs.
(*d*) Round the ends of handles, upon a very broad wheel, holding about 20 forks in the hand and pressing with ends of forks, prongs against the body.

At this stage, the forks were "set."

Polishing.—The polishers are always experienced men, and each individual carries the whole process through from the edge-glazed condition

* The author desires to acknowledge his indebtedness to the Orfèvrerie d'Ercuis, through whose courtesy the opportunity to visit was afforded.

to that ready for plating or for colouring. The work of polishing is much sub-divided, and several different sized leather wheels and brushes are used. To facilitate changing wheels, screwed ends of the spindle with buffs already mounted are taken on or off by help of a "tommy" bar.

The leather used for the polishing wheels is soft, and is made up in different sizes from discs clamped between iron plates. Between operations the wheels are immersed in a tub of water, which keeps the leather in the requisite condition of softness. Pumice powder mixed with a little oil is used for the polishing process.

As a preliminary operation, each polisher always goes through his whole "livraison" and touches up on a glazing wheel with very fine emery any roughness of the edges left by the glaziers. After this, practically all the work is confined to the surfaces of the article.

The following description gives the sequence of operations in polishing and brushing.

A.—Polishing.

Forks.

1*st operation.*—Three leather discs fastened together between central steel washers (diam. of wheel about 6 to 7 ins.). Powdered pumice thrown up just like buffing sand. Very quick process doing all prongs at once.

2*nd operation.*—Leather wheel about 5 ins. diam. and 3 ins. wide, made of discs of leather clamped between iron plates. Back of prongs of fork.

3*rd operation.*—Same wheel for whole of edges of handle.

4*th operation.*—Same wheel for front of handle.

5*th operation.*—Same wheel for back of handle.

6*th operation.*—Similar wheel about 2¼-in. diam. and 4 ins. broad, cut diagonally so that the pumice easily adheres. Front of prongs and prong end of stem in front.

7*th operation.*—Same wheel, back of shoulder below prongs, and middle of stem at back.

8*th operation.*—Similar wheel only 1 in. diam. and 3 ins. wide. Front shoulder and bottom of prongs in front.

9*th operation.*—Same wheel. Edges in shoulders and end of stem.

10*th operation.*—Same wheel. Back curve of stem.

11*th operation.*—Brushes. Pumice with tallow and oil.

Spoons.

1*st operation*—Wheel about 2¼ ins. diam. and about ¾ in. thick with bevelled edges, held between steel washers. Cross-cut to hold pumice. Top (*i.e.* near point) of inside of bowl.

2*nd operation.*—Similar wheel, but about 1 in. diam and 1 in. wide, almost a ball. Bottom of bowl. (End of spindle detached part is screwed and the leather is kept on by a tiny washer and nut.)

3*rd operation.*—Large wheel, 6 ins. diam, 3 ins. wide. Back of bowl at top.

4*th operation.*—Same wheel. Edges.

5*th operation.*—Same wheel. Front of handle.

6*th operation.*—Same wheel. Back of handle.

7*th operation.*—Similar wheel, 4 ins. wide, 2¼ ins. diam. Edges of bowl and front of handle, stem. (Corners of bowl are done entirely by the subsequent brushing process.)

8*th operation.*—Same wheel. Bottom back of bowl and back of handle, stem.

9*th operation.*—Similar wheel, but 1 in. diam 3 ins. wide. Back bottom curve of stem.

10*th operation.*—Wheel 1¾ in. diam., 1¼ in. wide. Middle of bowl.

B.—Brushing.

Brushes last four to five "*livraisons*" or "*tâches.*" They are about 12 cms. diam. when new, and when worn down are still used for the second

part of process on spoons, the brushes are also put together in the shop, being bought in discs and held between steel washers.

Spoons.

Brush 12 cms. diam, except in fifth operation.

1st operation.—Sides of stem near bowl.

2nd operation.—Bowl complete at first with bowl point away from operation and then reversed to cover the whole bowl including the bottom.

3rd operation.—Shoulders.

4th operation.—Back of bowl.

5th operation.—With smaller brush 3 ins. for handle, front and back.

Forks.

Throughout with the smaller (3-in. brush).

1st operation.—Back of prongs.

2nd operation.—Front of prongs. Reversed to get into shoulder.

3rd operation.—Front of handle.

4th operation.—Back of handle.

All the work except that by *polissage* is done sitting. About 25 per cent. of the *polissage* process is done sitting.

APPENDIX II.

PHOTOGRAPHS OF WATTMETER RECORDS.

The following tracings from photographs are given in order that the reader may more easily understand the use that has been made of the Wattmeter records in this Report. As was pointed out, only those portions of the charts which refer to the work of roughing the bowls have been carefully examined, because they were a little less complicated than other parts of the work. Tracings are given not only of the work on the bowls of the spoons, but also of that on the backs of the handles, and it can easily be seen that the same tendencies are to be found here as manifest themselves in the work on the bowls.

It will be noticed, in the case of each worker, that at the end of the day the lines on the chart reach a higher point than at the beginning, and that the angles of the apex and base of the curves tend to be greater. This latter feature can be more easily recognised by comparing the distances between the curves on an arbitrarily chosen line. The 190 line will be found convenient for this purpose.

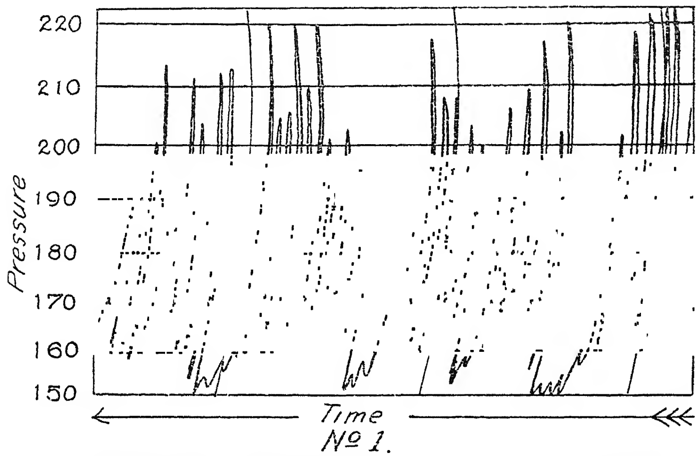
These differences illustrate what has been pointed out in this Report, namely, that as fatigue increases, effort, as manifested by pressure and duration of stroke, tends to become greater.

The difference between the two workers is clearly shown in these tracings. If a comparison is made between them when working on the same part of the spoon it will be seen that No. 23 is always putting forth more effort, although her output is always less than that of No. 15.

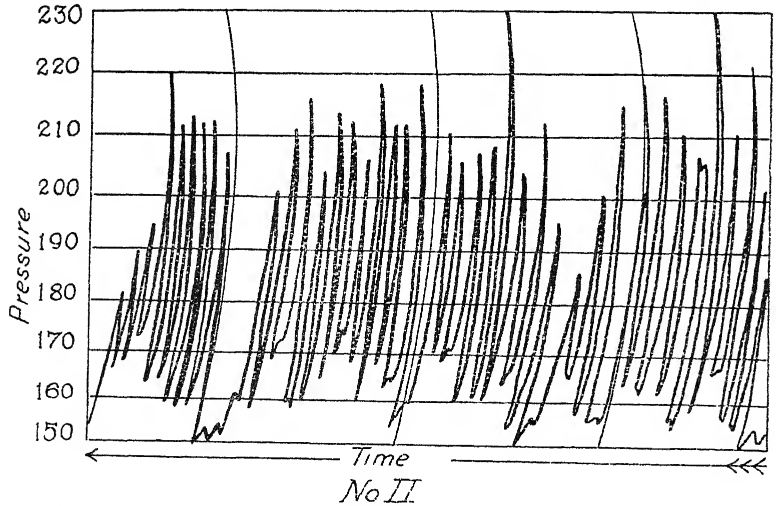
The width of each pair of curves represents the time required to perform the same task. It will be noticed that this is always longer in the evening than in the morning.

WATTMETER RECORDS.

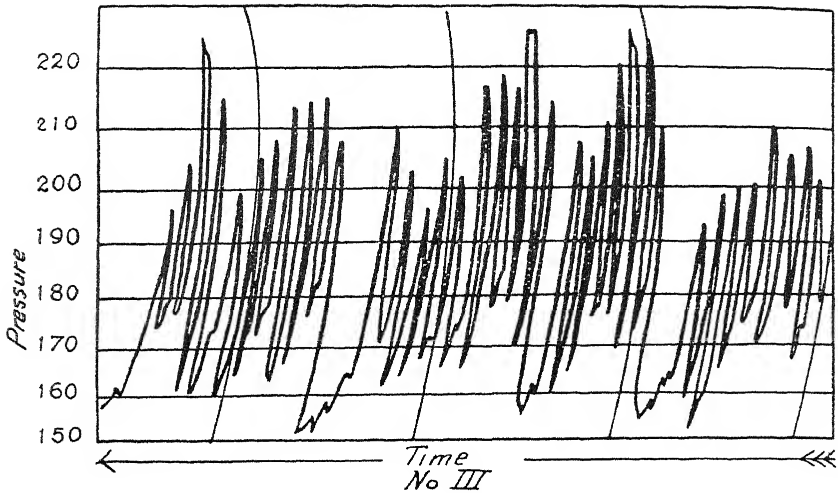
These reproductions are somewhat larger than the original charts. They should be read from right to left.



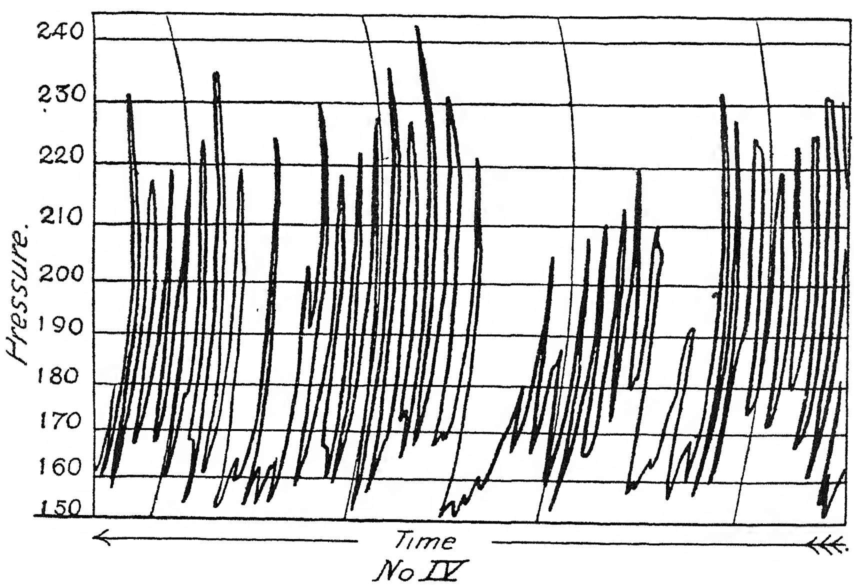
No. I.—Worker No. 15 doing the backs of handles at 8.45 a.m.



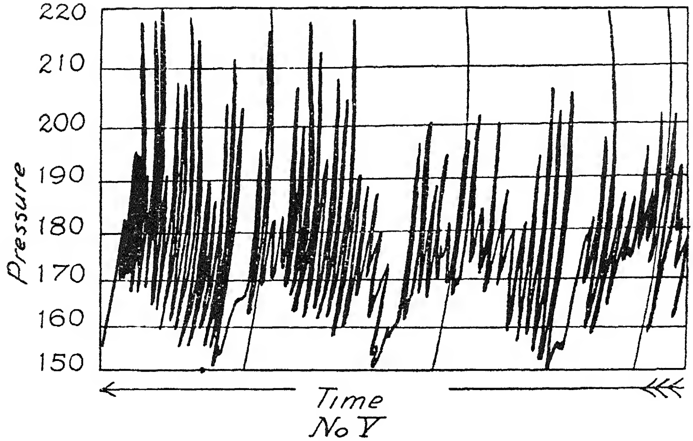
No. II.—Worker No. 15 doing the backs of handles at 5.15 p.m.



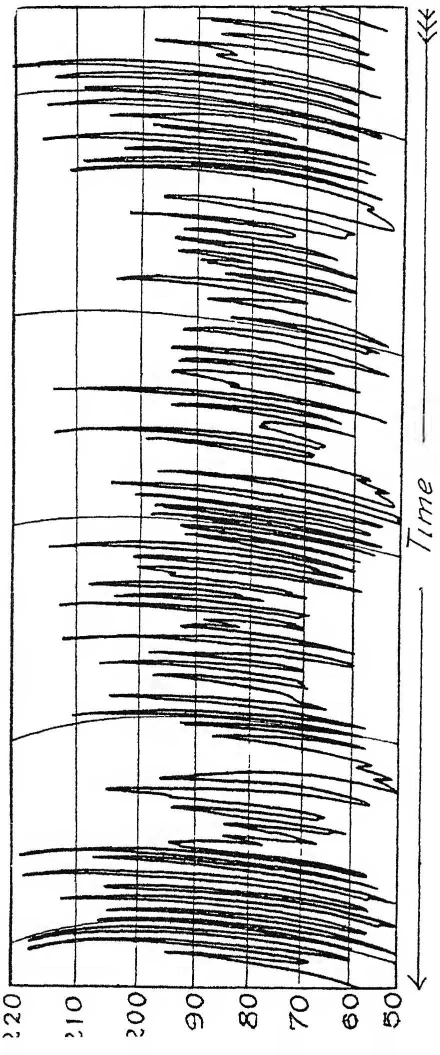
No. III.—Worker No. 23 doing the backs of handles at 9.45 a.m.



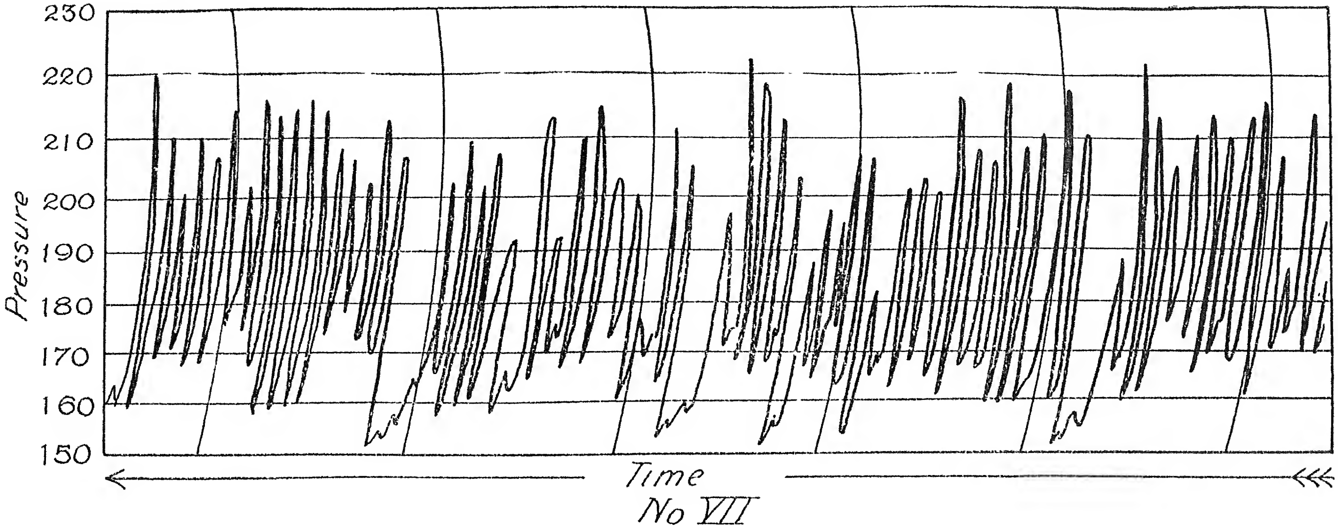
No. IV.—Worker No. 23 doing the backs of handles at 4.15 p.m.



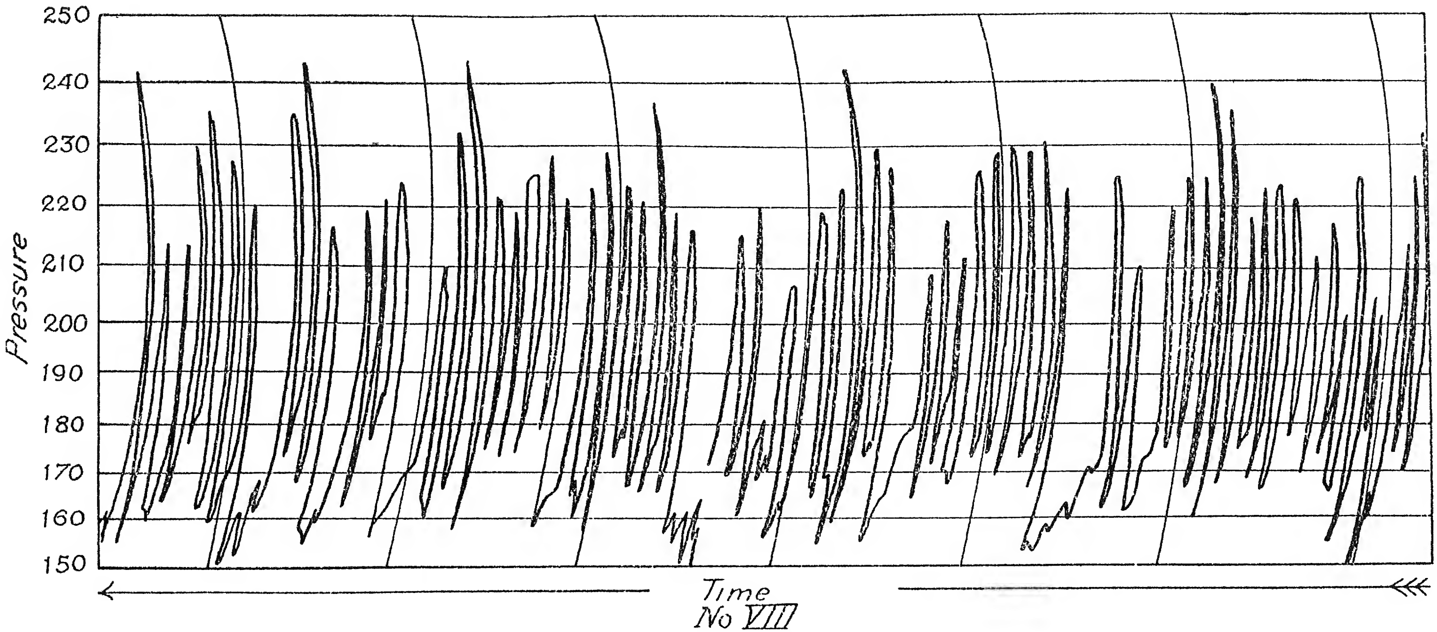
No. V.—Worker No. 15 doing four bowls at 8.45 a.m.



No. VI.—Worker No. 15 doing four bowls at 5.15 p.m.



No. VIII.—Worker No. 23 doing four bowls at 9.45 a.m.



No. VIII.—Worker No. 23 doing four bowls at 4.15 p.m.

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PREFATORY NOTE.

The Board, in their Preface to a previous report*, have already stated the reasons which induced them to pay some attention to Vocational Guidance and Selection.

The present Report, which includes three studies bearing on various aspects of the subject, illustrates the widely different qualities of the individual that may have to be taken into account in determining whether and how far he is suited for a particular type of work.

The first study, by Mr. B. Muscio, deals entirely with *psycho-physiological* qualities, and shews that high correlation exists between the ranking of individuals engaged in hand composing according to their executive efficiency, and their ranking according to the performance by them of certain selected tests.

The other two studies (by Mr. Muscio and Mr. E. Farmer respectively) are concerned with the *physical* side of vocational selection. The second deals with the range of muscular strength amongst about 2,300 youths in Manchester and industrial Essex, representative of those whose subsequent occupation will often demand considerable physical strength, and incidentally demonstrates the consistent difference in physical development that exists at all ages between youths in the two localities. It also describes in detail a method by which a useful estimate of physical strength can be quickly obtained. The third is concerned with the physical qualities required for non-muscular work and is a contribution to the question of how far dexterity in certain occupations is a function of physical type.

The Board wish to thank all those who have assisted their Investigators, often at considerable personal inconvenience, in carrying out the work described in this Report. In particular, they are indebted to the Essex County Council Education Authority and to Messrs. Crossley Bros., Ltd., Manchester, for the facilities granted to Muscio in the collection of the physical data embodied in Part B, to the managements of the four printing works for permission to carry out the tests described in Part A, and to Messrs. Pascalls, Ltd., of London, for their valuable co-operation in the investigation included in Part C.

January 1922.

* Muscio, B. (1921): Vocational Guidance (A Review of the Literature). *Industrial Fatigue Research Board Report.* No. 12.

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THREE STUDIES IN VOCATIONAL SELECTION.

A.—THE PSYCHO-PHYSIOLOGICAL CAPACITIES REQUIRED BY THE HAND COMPOSITOR

by

B. Muscio, M.A.

§1. Introductory.

In the past, the basic occupation in the printing industry has been hand composition.* This may be inferred from the fact that even now an apprentice spends practically the whole of his seven years' apprenticeship in the (hand) composing or "case" room.† It is true that, with the exception of "jobbing" work, a term applied to all composing except that of books and newspapers—for instance, to the composing of voting lists, office forms, handbills, theatre programmes—most modern composing is carried out on composing machines, linotype or monotype.‡ To be efficient, however—to be able to escape numerous possibilities of faulty work—the machine compositor, whether a monotype or linotype operator, is generally believed to require a training as a hand compositor; though it is not easy to determine how thorough such training should be. And the (proof) reader is in a similar position. Generally speaking, and with the exception of various minor occupations accessory to the main occupations, practical experience in hand composition seems to be necessary for efficiency throughout the printing industry.

At the present time, the great majority of those who become printing apprentices must remain throughout their lives hand compositors. The efficiency of the composing machines§ is such that the number of men required to operate them is relatively small, and the number of "readers" is always relatively small. Thus, there may be in any ordinary printing works five composing machine operators and five "readers" to fifty case room workers. The latter do not spend their whole time on "jobbing" (com-

* To a certain extent—*e.g.*, in many Scottish printing establishments—hand composition is still the basic occupation in the printing industry.

† The (hand) composing room is called the case room, because the metal letters employed in composition are arranged there, ready for use by the compositor, in compartments of wooden trays which are termed *cases*. *Cf.* below, §3, *ad init.*, p. 7.

‡ A certain amount of jobbing work is, however, done on specially adapted composing machines, and there is little doubt that most of it will be done in this way in the future.

§ A machine compositor composes, roughly, five times as fast as a hand compositor.

position); in addition to such work, they must, for instance, "make up" and "correct" the work of the machine compositors, and, in short, perform the tasks left over by the machine compositor which are necessary to prepare matter for the printing machines.*

In setting out to investigate the psycho-physiological capacities required in printing, it seemed best to begin with the hand compositor. This was partly because, as has been said, there are in the printing industry many more hand compositors than machine compositors and readers together; but also because individual differences in efficiency are generally greater among hand compositors than among other groups of workers in the printing industry. The latter fact is largely due, in the last resort, to the relative carelessness often shewn in accepting apprentices; the result being that a number of boys become "printers" who are not suited for printing, and, after having "drifted" into the industry, they remain as inefficient hand compositors. They have little chance of becoming inefficient machine compositors or readers, because in these occupations efficiency is emphasized. A hand compositor who is "tried" on the linotype, for instance, is soon sent back to the case room if he does not make good; and the same is true if he is tried as a reader. It thus happens that the case room of a printing works is the place in which the workmen constitutionally unsuited for the work of a printer are to be found; and as competent hand compositors are also to be found there, individual differences in efficiency in the case room are relatively large.

The main investigations here reported attempted therefore to determine the capacities required by the hand compositor. It must, however, be noted that in the future much of the work now done by the hand compositor will almost certainly be done on composing machines; and that the aptitudes required for operating these machines will differ more or less from those required for hand composition.

§2. Outline of Procedure followed in the Investigations here reported on.

The procedure adopted in the investigations may be described in outline as follows:—

(1) First, the work of the hand compositor was observed in order to determine, as far as observation would permit, what capacities are required for it. As a result, tentative suggestions were made as to what these capacities are (§3).

(2) Secondly, tests were selected or constructed which, it was thought, would indicate whether a person was well-endowed or poorly-endowed with these capacities (§4).

(3) Thirdly, these tests were given to groups of hand compositors who could be arranged by their overseers in an order of merit for composing efficiency. This was to determine if the good compositors excelled in

* *Cf.* also the third note to p. 7.

these tests and the poor compositors carried them out badly, as apparently should be the case* if they tested capacities necessary for the work of a compositor (§5). This comparison of efficiency in *composing* with efficiency in the *capacity tests* was made by the "correlation" method (*see below*, pp. 20, 51).

(4) Fourthly, tentative conclusions were drawn from these results as to what capacities are required by the hand compositor and what tests would be useful in selecting suitable apprentices for hand composition (§6).

§3. The Work of the Hand Compositor.

The general nature of the work of the hand compositor, who will henceforth be referred to simply as a compositor, may be indicated briefly.

The compositor, who works standing,† faces a "frame" on which are two "cases," known as the "upper" and the "lower." These are wooden trays divided by slats into compartments of different sizes in which are placed the different letters, spaces, punctuation marks, and other signs required for printing. The lower case usually contains the small letters chiefly, the upper the large and small capitals and figures, though there are several "lay-outs" in use. As he composes, the compositor holds in his left hand his "composing stick,"—an instrument for receiving the letters as they are set up; and uses his right hand (and arm) to carry the letters to the stick from their compartments in the cases. Since he has thoroughly learnt the lay-out of the cases during his apprenticeship, he never hesitates over the precise location of any type, and consequently the greater part of his time as a journeyman, at least when composing,‡ is spent in making movements with his right hand and arm between the compartments of the cases and his composing stick,—transferring type from the former to the latter. When about a dozen lines of type have been set up in the stick they are taken out of it, and the process is repeated, the various "stick-fulls" being laid together in appropriate relation. The matter is then measured

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* The suggestions of (1) might be correct and yet no correlation be shown here between efficiency in the tests and efficiency in composing, either because the tests of (2) did not test the capacities they were supposed to test or because the order of merit for composing efficiency of (3) was unreliable.

† Southward, in *Modern Printing*, (1915 Edn.). Vol. I., p. 158, says that varicose veins are often caused by the compositor standing in such an attitude that the weight of the body falls on one leg. It is interesting, also, that in the model apprenticeship indenture drawn up by Chas. T. Jacobi for the London Master Printers' Association, it is stipulated that the master shall be under certain obligations to the apprentice so long as the latter is not prevented from transacting his master's business by reason of *lameness* (among other things). *Ibid.* Vol. II., p. 334.

‡ About 25 per cent. of a compositor's work consists of "distribution" —replacing types in their respective boxes after the actual printing has been done. Owing to the nature of machine composition, however, this amount should be smaller in the future.

off into pages, &c., transferred to the "imposing"* surface and "locked up" in "chases." These are rectangular iron frames in which by means of a system of wedges composed matter is made fast and rendered portable. They are of different sizes to suit different sorts of work. If a single page is to be printed a small chase is used, the composed matter being placed within it, as it lies on the imposing surface, in such a way that there is a margin between the matter and the chase on every side. Part of this marginal space is then filled with "wedges," called, according to their form, "furniture," "sticks," and "quoins." When more than a single page is to be locked up the process is essentially similar, the difference being that "wedges" have now to be placed between the "pages" of type as well as between these and the sides of the chase. The locking up must be done so tightly that the type will not work loose when the filled chase, called a *forme*, is carried about or placed in the printing machine,—to which the formes go after "corrections" have been made.

Observation of the compositor's work (thus briefly described) suggested that certain capacities were required for it. In enumerating these we may begin by noting two "capacities," the importance of which is beyond doubt, and then proceed to indicate others whose relevance to this work would seem to need demonstration.

(1) First, then, there is no doubt that the compositor should possess good eyesight; few occupations make greater demands upon sight than his. Defective eyesight would almost certainly give rise to nervous disturbances of one sort or another.

(2) Secondly, a compositor should certainly possess physical strength somewhat above the average as the handling of formes is often heavy work.

(3) Thirdly, a compositor seems to require right hand and arm dexterity in a relatively high degree: the capacity to pick up small objects with the fingers of the right hand and to make rapid movements with the right arm. If certain persons were naturally possessed of this capacity in a relatively high degree they would seem to be, so far, relatively well-adapted to the work of composing.

(4) Fourthly, a capacity for rapid visual observation (distinct from "good eyesight") seems to be required. As each type is taken from its compartment in the case the compositor glances at it, chiefly to determine how it should be turned about so that the letter or other sign will be "right" when printed. Relative slowness of visual observation would seem therefore to prevent the compositor from becoming an expeditious workman. Again, this capacity seems important in the reading of "copy"—it has long been known that, among persons who read much, some read about four times as fast as others. Making "corrections," also, seems to require rapid visual observation in a high degree.

* "Imposing" consists of arranging the pages so that, if printed on a sheet, they would be consecutive when the sheet was properly folded.

(5) Fifthly, there seems to be required for composing a relatively high degree of "immediate memory": the capacity to hold material in the mind for a short interval. Whenever the compositor looks at his copy his composing is temporarily stopped or slowed down, and such stoppages or retardations often consume much time. Hence, the fewer they are the better, and it would seem that they might be relatively few if the compositor were able to hold in his memory a relatively large number of words while he sets them up.

(6) Sixthly, the compositor seems to need a relatively high degree of the capacity to estimate size and form. In the locking up of matter in chases actual measurements of "furniture" and "sticks" must often be made, but the "quoins," the real *wedges*, are not *measured*. Quoins of all sizes are kept together in drawers, and the compositor selects from among them at any time those that *seem* to him of suitable size for his particular job. If he chooses unsuitable sizes he must select again, and a certain amount of turning over of quoins is sometimes necessary before he obtains exactly what he wants. And in addition to its relevance to locking up, the capacity to estimate size and form seems to be highly important in all jobbing or display work, especially in such work as the setting up of magazine advertisements, the essence of such composition being the effective utilization of the space at the compositor's disposal.

(7) Seventhly, at least a moderate degree of "general intelligence" seems necessary, though the precise degree relative to other occupations is a matter requiring extensive investigation. It may be noted that the general use of composing machines for books and newspapers is limiting the (hand) compositor's work to jobbing or display, and while this makes no tremendous demands upon general intelligence, it does demand the capacity to understand and to follow instructions precisely and to adjust the mind constantly to situations possessing some novelty. Each piece of display work is a new problem and the rules for its solution are not altogether mechanical. There is opportunity for much individual judgment and taste.* It would not be surprising if a poor jobbing compositor at the present time were always found to be relatively unintelligent.

In suggesting the importance of general intelligence for the setting up of display work, it is not meant that this is the only part of the compositor's work in which it is required. It would appear to be useful also, for instance, in the difficult work of "justifying" the lines of type in the composing stick: that is, making them of exactly the right length. Technical reasons necessitate that this should be done with great accuracy. Doubt-

* In some printing works the jobbing compositor exercises practically no individual judgment, his work being to compose in exact accordance with the instructions of a "planning department." In such conditions he requires a lesser degree of general intelligence than where he is supposed to plan the work himself (determining, for instance, appropriate kinds and sizes and arrangements of type for an advertisement). These latter conditions are, at present, the more common—in England at least.

less visual observation comes into play here, and also sensitivity to pressure. The final letters of a line must fit into the stick neither too tightly nor too loosely, and they should fit in equally tightly in all lines. The compositor seems, to superficial observation, to carry out this "justification" largely by "feel" (touch and pressure sensitivity) aided, of course, by visual observation, but the judgments that the "feel" is or is not satisfactory would appear to depend for their accuracy to a considerable degree upon general intelligence.

§4. Capacity Tests.

After observation of any work has yielded suggestions as to the capacities required for it, these suggestions should be subjected as far as possible to the test of experiment. For this purpose we require capacity tests, and, for composing, the following tests were tentatively selected or constructed. (No attempt was made to verify the relevance to composing of the capacities numbered (1) and (2) in the preceding section, since their importance appeared to be beyond all doubt.)

1. *Match Stick Insertion Test.*—For testing the capacity numbered (3) in §3.

The subject (the person being tested) was provided with a board containing rows of small holes into which he was required to insert match sticks with his right hand. These were taken one by one from a box placed, first, at arms length from the subject, and secondly at a much shorter distance. The score was the number of sticks inserted, 30″ being allowed for each position of the match box.*

2. *Cancellation Tests.*—For testing the capacity numbered (4) in §3.

Two tests were used. (*a*) The first consisted in striking through with a pencil every e in a page of senseless unaccented French. The score was the number of e's cancelled in 2 minutes, minus 2 for each error. (*b*) The second was the test known as the Woodworth and Wells "number group checking" test. The subjects were given test papers on which were printed seven vertical columns of six-place numbers, and they were required to underline each six-place number containing both a 2 and a 9.† The score was the number of six-place numbers underlined correctly in 2 minutes, minus 2 for each error. The subjects were instructed to work down the columns beginning on the

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* It is important in giving this test that the match sticks should always lie evenly side by side, that is, parallel to one another. If they are jumbled together, the chances are that some subjects will get a much more favourable jumbling than others. The only way to equalise the difficulty of the test in this particular is to see that the sticks are *never* jumbled.

† Using this Woodworth and Wells blank, any digits may be selected for "cancellation"—not necessarily 2 and 9. Also, it is not necessary to select *two* digits; only one may be selected, or three, four, five or even six. Digits differ in the ease with which they may be perceived.

extreme left. (It is essential, if the performances of different persons in such tests as these are to be justly compared, *that the different persons should work by exactly the same methods.* For instance, no adequate comparison of the relative abilities of any two persons to perform this number group checking test could be made if one person had worked down the columns vertically and the other across the columns horizontally.)

The blanks for these two tests are here reproduced.

Cancellation Test a.

autrefoi race de marins chemin de cette montee un trouver
dans ses voyages chez peu abriter ses derniers et automnes
lointains cette toujours de ce coin de terre femme souvenir
nulle part il rien plaisir commode legitime celle etait petite
comme la demeure rivage fortune de trouver une ses plus
nous ouvert pour force de que cette chapelle de bonheur
commence et qui est le but de ceux reconnaissants remplie
serait est un long effort et depuis epoque donnent regarder
vie un rude labeur de chante cantique premiere se maisons
et plus rare de traversent retour une tremblantes au plateau
et toute des offrandes des humaines etaient sur le dispute
sauves du rage pouvait etrangement eu age voisines le cote
la bonne de sage sacre maison que avec independance en
marin et le jardin sauvage chretiens choses entre ce revoir
le nourriture prenait que juste personne et cher laissait faire
de huit jours hommes se contentent une contres heures est
plein dit vraiment ne chiens toutes les donnent desirer cela
que de chagrin faut que lesaient leurs idees lieu prouve
comme fait bien des ete gens souviendra utile le longtemps
remontrerait chien ce qui se soutenir voyait bien que entre
animaux aller de que prouve chose que les monde cette
pour cela les matelots disaient entre comme terre le fallait
voulait etre bon avec lui faire la traversee dedaigneux cela
pendant ferait croire dix bateaux ennuye politesse ce etait a
aussi parfois le perdu que ces chien bien des etrangement
toujours de qui bien egal le caressait exacte peuples rendait
mousse ne la gre courir enprendre possession de une ces
au lieu que cela lui ete fache comme beaucoup uniquement
en savait verite yeux que toutes les derniers sommes voulait
temps du bon en passerelles comme jappant et en etaient
aurait de baptises de lui laquelle reve besoin coiffures des
plancher arrives en bonne sante etait ces de se beaucoup
avaries et souvent aboye en dormant heureux quatre et en
terre solide vaches est aussi celui des comme vieux sombre
flairant le pour des te faire peine soutinrent servaient forces
nombre de siecle ta trace vaisseuax en le grandes attentions
dis pas rarement flottes francaises je ne te commerce parce
devait mais que chien me bien fier toupet nombrement bleu
chose ce cet effronte fait en monuments a detailee manqua
sautant une que bien chiens copain leur demeura est entre

Cancellation Test b.

(The Woodworth and Wells number group checking test.)

983642	168379	694517	253914	745682	158923	729648
426357	372159	754936	297835	627519	786531	731469
654173	947386	589761	134852	146237	194526	936425
837162	691324	814536	326175	368792	549826	572194
458671	971648	479612	495683	784295	817243	916328
275148	318495	635728	596873	982563	431289	381647
513978	182765	615832	851279	498136	356719	412789
197584	563792	748315	861395	421856	973124	125437
918654	846975	453867	281463	213956	651274	526987
397841	961872	248691	574389	532416	723964	473519
872351	327984	437528	864712	825916	682543	534169
923871	632791	765429	235849	672834	295481	349257
867314	462758	486592	198537	871596	164985	247153
963458	981374	156843	259671	762491	983567	579361
345962	941258	182653	561487	435781	179428	731825
672389	346521	427163	281937	672539	985273	956142
312876	853926	587436	296851	784623	875126	513647
934612	739548	843216	215367	916483	294378	768914
954178	371629	529817	436978	123874	957641	682917
719325	294736	639187	286415	593182	297568	145389
594231	389254	196235	825749	461289	378652	672841
349716	427395	138962	268794	524617	358472	319546
714932	759431	382145	853624	714529	635819	237465
649752	718254	596743	862934	851763	329418	495867

3. *Immediate Memory Tests.* For testing the capacity numbered (5) in §3.

Two tests were used. (*a*) The first was a "substitution" test. In this test the subject was required to write above each letter in a page of widely-spaced letters a specified digit in accordance with a "substitution key" printed at the top of the blank. The score was the number of "substitutions" correctly made in 3 minutes. Performance in this test depends, though not entirely, upon the capacity to hold the key "in memory." (*b*) The second test was a test of "immediate memory *span*." Sentences gradually increasing in length were shewn one at a time for 4 seconds each to the subject who was required (immediately after the exposure of any sentence) to write down as much as he could of what he had read. The "immediate memory span" as indicated by this test was the average number of words correctly reproduced—deductions being made for errors of various kinds (interpolations, omissions, transpositions). This test is more similar to an important part of the actual work of composition than the former one: it corresponds almost exactly to what the compositor calls "taking a mouthful" of copy. It is almost unaffected by rate of reading as the average person is able to read more in 4 seconds than he can reproduce.

The material for these two tests is given on the next two pages.

4. *Form Board Test.*–For testing the capacity numbered (6) in § 3.

Thirty blocks, most of them slightly wedge-shaped,* were cut from a piece of board. The subjects were given the board with the blocks distributed in front of it (in standard positions), and they were required to put the blocks into the holes from which they had been cut. The time taken for this was used as the score. it being assumed that errors in estimating size and form would shew themselves in an increase of the time required to fit the blocks into their appropriate holes. The scoring of a form board performance is, however, somewhat difficult (*cf.* below, note to p. 21).

5. *Directions Test.*—For testing the capacity numbered (7) in § 3.

This consisted of a number of printed "directions" gradually increasing in difficulty, the task being to follow these directions *precisely*. Marks were allotted according to the difficulty of the directions, the score being the number of marks obtained in 6 minutes work. ("Directions" tests have been shewn to correlate highly with other measures of "general intelligence.") The blank used for this test is given on pp. 16 and 17.

* The blocks were all more or less similar to actual quoins.

(*a*) *The Substitution Test Blank.*

2	*5*	*3*	*7*	*9*	*6*
P	F	B	M	S	L

P	F	B	M	S	L	F	M	L	S
P	B	L	S	B	M	P	F	S	M
L	B	F	P	B	P	M	L	F	S
F	M	S	P	L	B	B	S	L	M
P	F	F	M	S	P	L	B	L	P
S	F	M	B	B	S	M	P	F	L
B	S	L	M	F	P	F	B	L	S
P	M	M	S	L	P	B	F	B	L
S	M	F	P	B	F	P	L	S	M
L	M	S	B	F	P	S	B	F	M
P	L	M	P	L	F	B	S	M	L
S	P	F	B	L	P	S	F	B	M
L	F	S	P	M	B	F	M	B	S
P	L	P	S	L	M	F	B	L	F
S	B	M	F	F	L	S	B	P	M
P	M	F	S	L	B	L	S	M	F
B	P	S	F	P	M	B	L	F	S
L	B	M	P	P	B	L	F	S	M
F	S	L	P	M	B	B	L	M	P
S	F	F	L	S	B	M	P	M	S
L	M.	B	P	F	M	P	S	L	B

(*b*) *Test of Immediate Memory Span.*

(Each sentence exposed for 4″ : reproduction required immediately afterwards.)

Sample.

There are more things than one imagines beneath the surface of the sea.

1.

You are pretty sure to find something suitable among the last three hundred shewn you.

2.

The fame of any discovery that can remove depression of spirits is surely worth spreading.

3.

If dust flies out, you know that the structure is old and insanitary; but do not be at all discouraged.

4.

I am thirty-seven, an architect in a small way, and I live with my family in a house built by another on the Northern Estates.

5.

There was once a doctor, who shall be nameless, and he sold his practice to a certain young man to whom he said that it was worth four hundred pounds a year.

6.

At the moment of writing, the weather is not very appreciably colder, and we therefore continue to receive accounts of robins' nests in motor-bonnets, primroses by the river's brim, and gooseberries on Dartmoor.

7.

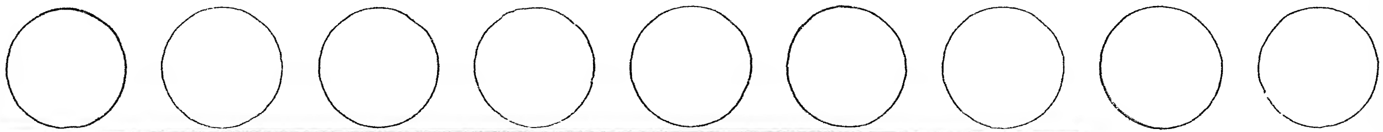
We are glad to observe that the bare suggestion that any British journal could be persuaded to publish advertisements in the form of news or editorial comment has been received by our Press with a cry of horror and indignation.

Directions Test.

1. Put a stroke through the g in *tiger*.
2. Make two crosses under the shortest word in this sentence.
3. If the sum of 3 and 7 is less than 12, put the figure 2 between these two dots . .
4. Put a circle round the fourth figure to the left of 2, and a line under the second figure to the right of 5. 7 8 9 5 8 3 1 6 2 0 9 7 4
5. Draw a line round each word below in which an **e** follows *immediately* the letter **p** or the letter **g**.

describe, perchance, forget, effect, cognate, pigeon, compensate, raffle, penguin, except.

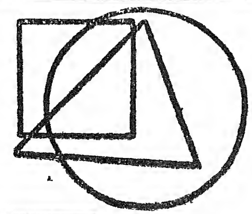
6. If Z is the last letter of the alphabet, and if B does not come before A write NO under this line . .
7. In *this* sentence there are precisely forty-eight letters.—If a particular word in the sentence had been omitted, the number of letters would have been forty—*Find this word and put a line under it.*
8. Look at these circles. The one on the left is No. 1, the next No. 2, the next No. 3, and so on.—Draw a line from the centre of circle No. 3 to the centre of circle No. 8, so that it passes above circle No. 4, under circle No. 5, through circle No. 6, and above circle No. 7.



9. Below is given, in irregular order, the whole of the alphabet, except one letter.—Find out what the missing letter is, and write it exactly under the letter which would come just before it if the alphabet were set out properly.

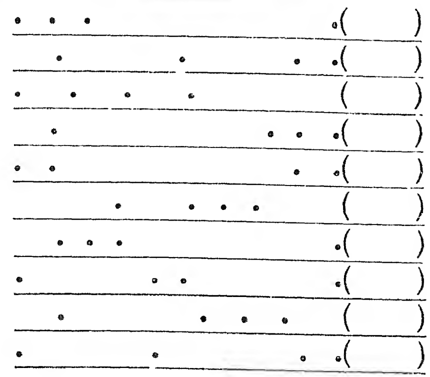
E J O Z B H M P A D V I U K C X T Y Q W S N L G F

10. Look at the square, triangle and circle. Put 2 in the space which is in the circle but not in the triangle or square; put 5 in the space which is in the triangle and circle but not in the square; and put Z in the space which is in the triangle, circle and square.



11. Just above each of the lines on the right are 4 dots. The dot on the extreme left is No. 1, the next is No. 2, the next No. 3, and the one on the extreme right is No. 4.

Whenever the distance between No. 1 and No. 2 is less than that between No. 4 and No. 3, put a minus sign (—) inside the brackets at the right; when the distance between No. 4 and No. 3 is less than that between No. 1 and No. 2, put a plus sign (+) inside the brackets; and when the two distances mentioned are about equal, put O inside the brackets.



To the possible objection that tests of the kind just described would *not* indicate the *aptitudes* required for composing because they are tests of capacities which have been *developed by* composing and have received much *practice*, two replies may be made.

(*a*) First, the aim of the present investigations was to determine what capacities are required for composing. Now to say that a particular capacity has had much practice in the work of composing implies that it is, as a matter of fact, exercised in that work,—that it is one of the capacities *required for* composing. If it were not, it would not have had the practice that it is said to have had. That is, one cannot, in general, assert that a capacity has had practice in any work without implying, at the same time, that it is one of the capacities required for that work, and consequently that the person who possesses it by nature in a high degree will, so far, be fitted for that work.

(*b*) Certain tests, among which, for instance, are cancellation tests, show a high correlation* when the *first* performance is correlated with performances *after practice has been eliminated.* In an experiment by Hollingworth (*The Psychol. Rev.*, Vol. 21, p.4.) a *cancellation* test was worked 175 times by each of thirteen subjects who formed a homogeneous group (college men and women). The first performance correlated $+\cdot 665$ with the average of the last five, and the average of the first five $+\cdot 682$ with that of the last five. (These coefficients would possibly have been higher had the subjects formed a less homogeneous group.) Hence we may infer that if a group of compositors, presumably practised in the capacity exercised in *cancellation*, had been given the *cancellation* test when becoming apprentices and again ten years later, the majotiry of those above the average on either occasion would also have been above the average on the other. That is to say, practice, in certain tests at least, raises the performance of everyone while leaving *relative* performance much the same.† It is of course necessary to find out of what tests this is true. The *match stick insertion* test is apparently similar to *cancellation* in this respect. In a homogeneous group of sixteen school girls (aged about fourteen), the average of the first three performances of this test correlated over $+\cdot 5$ with the average of the last three (the 13th, 14th and 15th).

If, therefore, efficiency in composing correlates highly with efficiency in either the *cancellation* or the *match stick insertion* tests, we can infer that a boy whose performance in these tests before he becomes a compositor is relatively high, will, so far, make a relatively good compositor; that he will be relatively highly endowed with certain of the capacities required for composing.

* For the meaning of *correlation*, see below, p. 20.

† In a test which consisted of finding the products of two-place numbers by means of a key, Thorndike found that those who did well in the preliminary performance not only retained their positions after considerable practice, but improved at a *greater rate* than those whose preliminary performance was poor.—*Am. J. Psychol.*, 1916, 27, p. 553.

§ 5. The Experimental Investigations.

To obtain evidence concerning the value of the tests, described in the preceding section, for diagnosing the capacities required by the compositor, investigations were made in four printing works where facilities were given by the management. The employees were informed in each case as to the precise object of the investigations and willingly cooperated by submitting themselves to the tests. It was impracticable and unnecessary to give the tests to all the compositors in these establishments; they were given to 25 in the first, to 24 in the second, to 40 in the third, and to 11 in the fourth. These works will be referred to in the sequel as PWA, PWB, PWC, and PWD. All the compositors tested at PWA and PWB were men, at PWC they were almost all men, and at PWD they were all women.

The tests were given the compositors individually in as quiet a room as could be found—the time occupied being above three-quarters of an hour for each compositor. Precautions were taken against anything that might render the results unreliable, and while some unsatisfactory conditions could not be entirely removed, it is believed that these had no harmful effect upon the greater part of the results. After the tests had been given, the compositors were ranked according to the excellence of their performance in each of them; that is, the compositor who had done best in a given test was given the first rank for it, the compositor who had done second best was given second rank, and so on, the compositor who had done worst being placed in the bottom rank.

The compositors were then graded according to their efficiency as compositors by their respective overseers (works managers and case room superintendents).

The making of these "orders of merit in composing" was a difficult task. The overseers had of course no doubt that certain men were superior to others as compositors, but the method to be pursued (the "correlation" method) required fine gradings, and to obtain these was not easy (for some account of the difficulties, *see* Appendix II.). Much care had to be taken therefore in the attempt to make these "orders of merit" reliable, and finally the groups at PWA, PWB and PWD were arranged fairly satisfactorily by their overseers in rank orders according to composing efficiency,—the most efficient in the first places, the least efficient in the last places, and the moderately efficient in the middle places. At PWC, such a grading could not be obtained owing to the fact that the work of a compositor was there divided into several parts, one man doing one part and another another part. Thus, a small group of men was engaged on display work only, another group on "making up," another group on "corrections," and still another group on "stone" work.*

* (*Imposition.*) The imposing surface is called "the stone" because it used to be made of stone, and "working on the stone" is now used as equivalent to "imposing" (it includes locking up in chases).

Men had been placed in one of these groups rather than another according to the overseer's judgment as to their aptitudes. This *de facto* grouping allowed of some estimation of the capacities required *for different parts* of a compositor's work.

Leaving PWC out of account for the present, there were now two sorts of gradings for each group of compositors: (1) the grading by efficiency in the psychological (capacity) tests, (2) the grading by efficiency in hand composing as determined by the overseers. These two sorts of gradings were compared and the results of the comparison are given below in correlation coefficients.

Correlation coefficients are numbers ranging between +1 and −1, which are employed to express a relationship between two or more factors. The nearer a coefficient approaches to +1 the closer in general is this relationship. Thus, the relationship found to obtain between height and weight might be expressed by a correlation coefficient.* Supposing that this coefficient were approximately +1, we could infer with approximate certainty that the tallest man of any fairly large group would be the heaviest and the shortest the lightest; and that if the whole group were arranged in an order from the tallest to the shortest, it would be found that this was practically identical with the order from the heaviest to the lightest. The actual correlation of height with weight is of course considerably less than +1: there are tall men who are not heavy and short men who are not light.

If now the correlation coefficient of efficiency in any psychological (or other) test with efficiency in composing were "large" and positive, we should infer (subject to certain other possibilities that need not be discussed here) that the capacity required for this test was important for composing; and we should expect that if only those boys were to become compositors who possessed a high degree of this capacity, the efficiency of compositors would (so far) be higher than it now is (seeing that in the past the possession of the capacities required for composing was not as a rule made the basis for accepting an apprentice). What then is a "large" correlation coefficient? This question cannot be answered satisfactorily without discussing statistical methods in more detail than is possible here, but it may give some suggestion of relative values if it be said (broadly) that a correlation coefficient may be regarded as "large" if it is not less than ·6, while if it is less than ·3 it may be regarded as definitely "small."

The correlation coefficients of efficiency in the tests and efficiency in composing will now be given. Not all the seven tests described in §4 were used at all four printing works. At PWA and PWB six of these were used, and at PWC and PWD a smaller number, though at the latter two works other tests

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* *See* Report B below, p. 51, where the calculation of a correlation coefficient is given.

were used also (chiefly for purposes of experimental "control"). Further details concerning the tests used at the different works, in so far as these are required, will be given below. The results for PWA and PWB are presented in Table I.

TABLE I.

Correlation coefficients of efficiency in composing and efficiency in each of six tests at PWA and PWB. ("p.e."="probable error." A coefficient should be at least 3 times its p.e. to be "significant.")*

Printing Works.	No. of Comps.	Cancellation Tests.		Substitution Test.	Directions Test.	Match Stick Insertion Test.	Form Board Test.
		e's (*a*)	2 & 9 (*b*)				
PWA	25	+·64 p.e.=·08	+·45 p.e.=·11	+·58 p.e =·09	+·57 p.e.=·09	+·57 p.e.=·09	+·56 p.e.=·09
PWB	24	+·59 p.e.=·09	+·19 p.e.=·14	+·50 p.e.=·11	+·60 p.e.=·09	+·56 p.e.=·10	—·16 p.e.=·15

At PWA each of the six tests, and at PWB four of them, yielded a "significant" positive correlation coefficient with composing. That two of the tests did not yield "significant" coefficients with composing at PWB is possibly not due to the fact that the capacities tested by them are negligible in composing, but to special circumstances and technical difficulties concerned with the nature of the tests.† Nevertheless, in dealing further

* These were calculated by the Pearson "product moment" formula adapted to rank differences This is given in the note to p. 51 below.

† Thus, with regard to the *number group checking test* (cancellation tests, *b*) it was relatively difficult to make the compositors understand clearly what it was they were required to do, and several cases of misunderstanding were observed to occur, even after what seemed adequate explanations had been given. If such misunderstandings were not distributed fairly equally among the different grades of compositors they might tend to decrease the size of the correlation coefficient. In addition, the correlation was decreased greatly by the "erratic" performances of two men, one of whom was among the first-class workmen, while the other was the poorest compositor of his group The first-class workman came nearly bottom of the group in this test, and the poor workman nearly top. The former was highly nervous in temperament, and nervousness appears to affect the present test in a marked degree, as may be understood when it is said that it is relatively easy to get the impression that one is doing the test badly. The latter was placed low as a workman by his overseer chiefly because of his lack of "intelligence" and "industry," defects which could not show themselves in this particular test, though in the test used for "general intelligence" (*the directions test*) this man was near the bottom of his group. If these two men are omitted from their group the coefficient of efficiency in the *number group checking* test with composing efficiency at PWB becomes + ·42, which is almost as high as the corresponding coefficient at PWA.

Concerning the *Form Board Test*, the difficulties were partly in scoring the results (*cf.*, above, §4, p. 15). Some compositors who appeared by

[*Continued on next page.*

with the data it appeared best to assume, for the present, that these tests were unsuitable for diagnosing composing aptitudes and to limit attention to the remaining four; though the *Form Board Test*, at least, would appear to deserve further investigation in this connexion. The two tests here laid aside were not used further in the present investigations.

The results for the four remaining tests were now combined. For it would seem that composing efficiency depends (partly, of course; it depends also on training; *cf.* APPENDIX I) upon the possession of a relatively high degree of the capacities required for *each* of these four tests and not simply upon the possession of the capacities required for one or two of them. That is to say, the aptitude for composing is complex and involves a group of capacities. The ranks of any compositor in the above four tests were therefore added together and his average rank in them was calculated. The averages thus obtained (which may be taken to represent the relative degrees of the *group* of capacities possessed by the different compositors) gave a new ranking of the compositors—a ranking for combined efficiencies in the four tests; and the correlation coefficients of this new (composite) ranking with that for efficiency in composing (at each works) was as follows:—

at PWA, $r = +\cdot 68$, $p.e. = \cdot 075$
at PWB, $r = +\cdot 74$, $p.e. = \cdot 060$

These coefficients are fairly "large," which suggests (so far) that the capacities required for the four tests are definitely *among* the aptitudes required for composing.

In combining the four tests in the way just described, it is assumed that they are all of equal importance for composing, and the question arises whether or not this is so. If we could be sure that the capacities involved in the performance of any one of these tests were different from the capacities involved in the performance of any other, the relative importance of the tests might be based upon the sizes of the coefficients which they separately yield with composing efficiency; that is, a test correlating with composing, say, $+\cdot 6$ should be considered of more importance than another correlating, say, $+\cdot 5$. But it is possible that different tests involve to some extent the same capacities. What we require to know, therefore, is the extent of the correlation between any one test and composing when

their actions in carrying out the test to have little "sense of form," obtained high rank in their groups owing to the method of scoring adopted. Inaccuracy in judging form and size was compensated for in these cases by a certain sort of dexterity, though not the dexterity required for composing. That is to say, though these compositors made gross errors in attempting to fit a given block into a hole, they made rapid movements, trying a block in various holes in succession until they found the right one. In this process there was very little judgment of size and form. It would seem, therefore, that scoring in this test should be on the basis of errors rather than of time, especially as in the compositors' work it is accuracy in the judgment of size and form that is the important thing.

everything common to that test and the other tests has been eliminated. A statistical method by which this knowledge may be obtained is that known as *partial correlation.** In the present case, partial coefficients of the individual tests with composing would indicate the degree of correlation between each test and composing apart from any correlation that might be caused by the other tests.

Partial coefficients with composing efficiency were calculated for the four tests yielding significant positive coefficients at PWA and PWB. The data required for this calculation consist of the coefficients between the tests themselves, and between each test and composing. These were calculated for each works separately, and the two resulting sets of coefficients were then averaged, these averages forming the basis for the calculation of the partial coefficients. It was thought that such averages would be more representative than the coefficients for either works taken by themselves. They are set out in Table II.

TABLE II.

Correlation coefficients of the tests with composing and with one another. Each coefficient is the average of two coefficients, one obtained at PWA and the other at PWB.

	Cancellation (e's).	Substitution.	Directions.	Match Stick Insertion.	Composing.
Cancellation (e's) -	—	+ ·59	+ ·43	+ ·23	+ ·61
Substitution - -	+ ·59	—	+ ·56	+ ·50	+ ·51
Directions - -	+ ·43	+ ·56	—	+ ·31	+ ·58
M. Stick Insertion -	+ ·23	+ ·50	+ ·31	—	+ ·56
Composing - -	+ ·61	+ ·51	+ ·58	+ ·56	—

The partial correlations obtained by means of the coefficients of TABLE II. are as follows :—

Cancellation (e's) and composing - $r = + \cdot 52$
Substitution and composing - - $r = - \cdot 19$
Directions and composing - - $r = + \cdot 42$
M. stick insertion and composing - $r = + \cdot 53$

The notable point in these results is the *negative* partial coefficient of *substitution* and composing. This means that the correlation obtained between this test and composing *directly* (+ ·51, TABLE II.) was really due to characteristics which it

* *Cf.*, G. Udny Yule, *Elements of Statistics*, Ch. XII. The general formula for obtaining partial coefficients is given on p. 238.

shared with some or all of the other three tests, since, when the influence of these tests was removed, all positive correlation of this test and composing disappeared. *This result illustrates the importance of calculating partial coefficients in all investigations of the present type.*

On the basis of these *partial coefficients,* values were now allotted to the various tests. *Substitution* was given the value *zero ;* that is, it was eliminated altogether. This was not because it would yield particularly inaccurate results, but because it was unnecessary; it duplicated certain parts of the other three tests. These other tests were given values proportional in each case to the size of the partial coefficient; the three coefficients were each divided by their sum, and the quotients, multiplied by 100, were taken as the maximum values to be given to "perfect" performances in the three tests.* This gave the following scale of maximum values :—

	Marks.
Match stick insertion test - - -	36
Cancellation test (e's) - - - -	35
Directions test - - - - -	29
Total - - - - -	100

These relative values were then allotted to the individual performances in the respective tests. The best performance in any test at either works was considered a "perfect" performance and given the maximum number of marks, and poorer performances were reduced to this standard. Finally, the compositors at each works were again ranked on the total scores (in the

* A more precise method of weighting the tests would be as follows :—

On elimination of the *substitution* tests the partial correlations become—

Composing and Calcellation (*Directions and Matchstick insertion constant*) - - - - - - - - $+ \cdot 50$

Composing and Directions (*Cancellation and Matchstick insertion constant*) - - - - - - - - $+ \cdot 38$

Composing and Matchstick insertion (*Directions and Cancellation constant*) - - - - - - $+ \cdot 50$

The regression equation from which we can determine composing ability from the results of these three tests is :—

$$(x_1 - \bar{x}_1) = \cdot 40\,(x_2 - \bar{x}_2) + \cdot 29\,(x_3 - \bar{x}_3) + \cdot 38\,(x_4 - \bar{x}_4),$$

where x_1 = composing marks $\quad \bar{x}_1$ = mean of all composing marks.
,, x_2 = cancellation marks $\quad \bar{x}_2$ = mean of all cancellation marks.
,, x_3 = direction marks $\quad \bar{x}_3$ = mean of all direction marks.
,, x_4 = matchstick marks $\quad \bar{x}_4$ = mean of all matchstick marks.

In other words, $\cdot 40$, $\cdot 29$ and $\cdot 38$ are the weights which should be given to the deviation of any particular man's performance in all three tests from the average of all performances in order to obtain his composing ability.

Application of this method gave results corresponding closely with those obtained by the method described in the text and embodied in Figs. I and II.

three tests) thus obtained, and these rankings were correlated with the ranking for composing. The coefficients obtained were—

at PWA, $r = + \cdot 71$ (p.e. $= \cdot 06$)
at PWB, $r = + \cdot 80$ (p.e. $= \cdot 05$).

Graphical representation of these final results is given in FIGURES I. and II. The straight diagonal line indicates a possible absolute correspondence between the rankings for composing and total efficiency in the three tests (an r of $+1$). The dots represent the individual compositors. The degree of correlation is indicated by the nearness of these dots to the straight diagonal line. If a dot falls on this line, the compositor indicated by it occupies exactly the same position in the test and work rankings. While this happens seldom, the distance

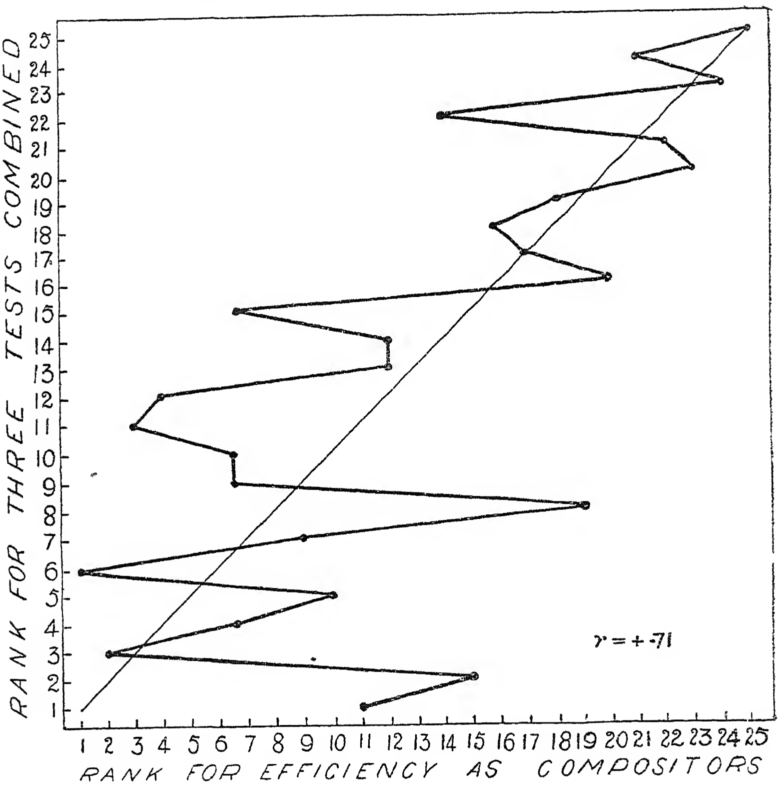

FIG. I.

Graphical representation of the degree of correlation at PWA between composing efficiency and total score in the *Cancellation*, *Match Stick Insertion*, and *Directions* tests.

The ordinates are the ranks for the tests :—that is, " 1 " indicates the *rank* of the compositor who made the best performance in the tests, " 2 " that of the ocmpositor who made the second best performance, and so on. The abscissæ are the ranks for composing efficiency. The position of the top dot, for instance, indicates that the compositor who was 25th in the tests was also 25th in composing efficiency.

of the dots from the line of perfect correlation is rarely considerable.

The value of the tests may, perhaps, be indicated more effectively by a rougher correlation method. This consists in arranging the compositors according to their efficiency in composing in three grades only :—

(I.) A class of good compositors;
(II.) A class of moderately good compositors;
(III.) A class of poor compositors;

and in comparing the average performances of each of these three grades in the tests. These average performances have been expressed in terms of their deviation from the average performance of *all* the compositors in each test (termed the *general average*) the compositors at each works being treated separately. That is to say, the average performance of all the compositors at each works was first calculated; then the average performance for each of the three classes of compositors separately; and finally, the average performances of these three classes at any works were expressed in terms of their

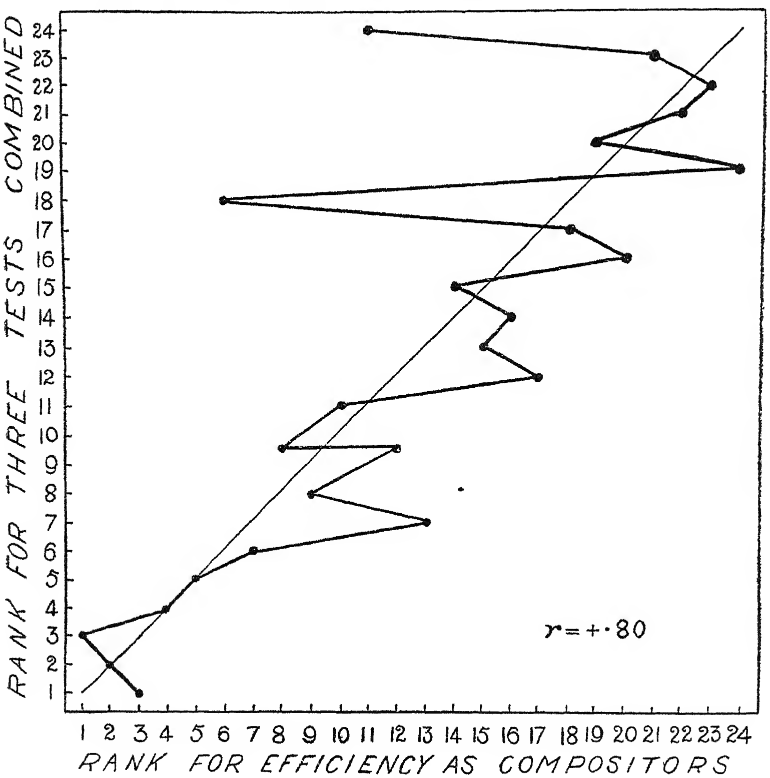

Fig. II.

Graphical representation of the degree of correlation at PWB between composing efficiency and total score in the *Cancellation, Match Stick Insertion,* and *Directions* tests. (Explanation the same as for Fig. I.)

deviation from the general average of that works. The results for the *four* tests yielding significant positive coefficients at both works (*substitution* has been included here for comparison) are presented graphically in Figures III. and IV. They show that the tests distinguish clearly between the three classes of compositors.

Certain details of the performances of the compositors in the *Cancellation*(e's), *Match Stick Insertion* and *Directions* tests taken together, are of sufficient interest to be added here. When these tests are given the values stated above,* the maximum score obtainable is 100, which would be obtained by a compositor who did all three tests "perfectly." The best and poorest

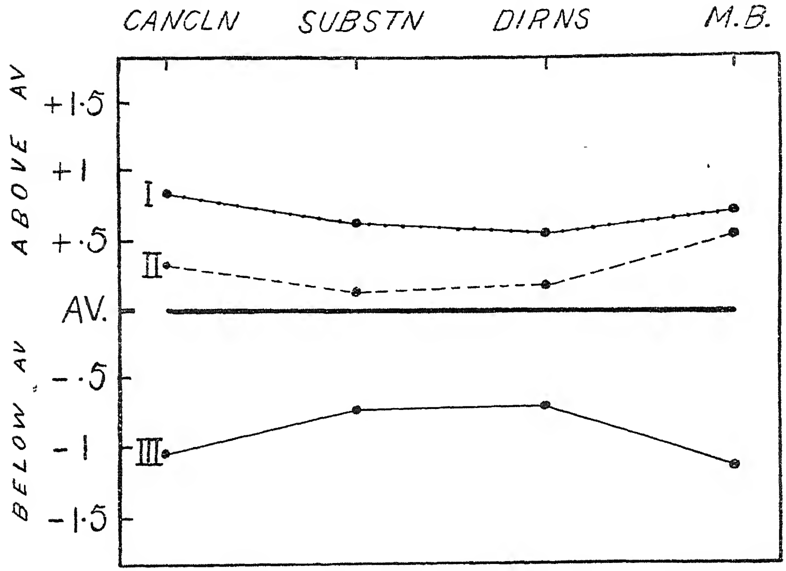

Fig. III. (PWA).

The heavy horizontal line represents the *average* performance of all the compositors at PWA in each of the four tests indicated along the top of the figure. The dots joined by the lines marked I., II. and III represent the *average* performance in these four tests of the Grade I., II. and III. compositors respectively. The unit for the ordinates is the *mean variation* of all the compositors from the general average. Curve No. 1 indicates that the Grade I. compositors at PWA—the best 8 work men out of the 25—were *above* the general average in all four tests. The same is true for the Grade II. compositors—the middle 9—though these are closer to the general average than the Grade I. compositors. Curve No. III. indicates that the Grade III. compositors—the poorest 8 in composing—were *below* the general average in all four tests. Their average deviation below this general average is approximately once the mean variation. The compositors who form Grade II. (on their work) thus yield an average performance in these tests between that of the Grade I. and the Grade III. compositors. (The mean variation *within* the grades at PWA, however, is fairly large. *See* Table III. below.) This figure represents 25 compositors at PWA).

* page 24

scores actually obtained (in these tests) at each works, together with the average scores for the three grades of compositors (*see* preceding paragraphs) at each works are given in Table III.

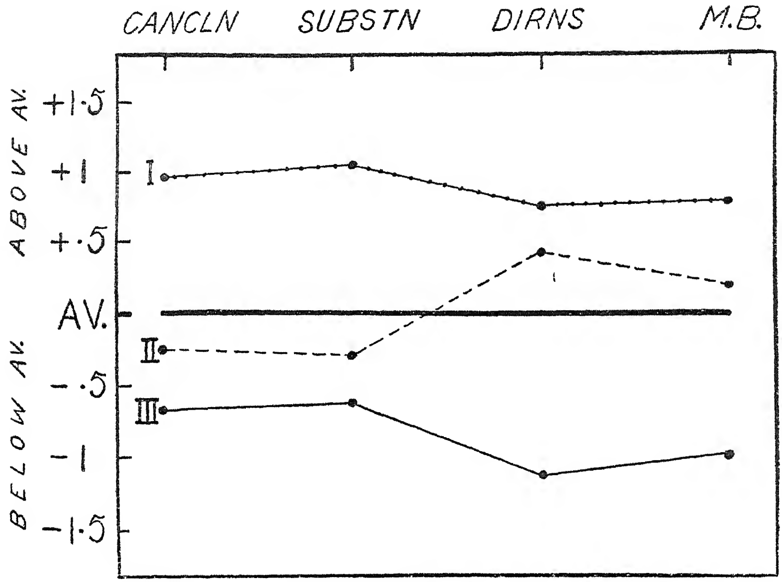

Fig. IV. (PWB).

The explanation of this figure is the same as that of Fig. III. Grade I is, in this case, constituted of the 7 best compositors, Grade II. of the middle 10, and Grade III. of the poorest 7. Grade II. is here more nearly identifical with the general average. (The mean variation *within* the grades in this case is relatively small. *See* Table III. below.) This figure represents 24 compositors (at PWB).

TABLE III.

Works.	Highest possible Score.	Best Score obtained.	Poorest Score obtained.	Average Score Grade I. Comps.	Average Score Grade II. Comps.	Average Score Grade III. Comps.
PWA	100	94·6	40	77 m.v. = 5·4	74 m.v. = 11·6	58·5 m.v. = 8·2
PWB	100	90·8	53·1	84·2 m.v. = 3·5	78·5 m.v. = 4·9	62·9 m.v. = 4·9

It will be seen that a large range of performance in these tests was shown; also that these three tests (together) distinguish particularly clearly between the Grade III. compositors and the remainder (the difference between Grade III. and Grade II. is considerably greater than that between Grade II. and Grade I.). In these investigations, Grade III. included 30 per cent. of the compositors tested; and it is obviously important that the

tests drew so clear a line of separation between these compositors and those better fitted for their work.*

Now. it will be noted that the three tests finally retained (the *Cancellation* (e's) *Match Stick Insertion*, and *Directions* tests) do not specifically test *immediate memory*. It was assumed in the earlier part of the investigation that the *substitution test* would test this function, but we may conclude in view of the results given above that the immediate memory tested by this test is not the sort of immediate memory required for the compositor's work. "Immediate memory *span*" (*see above*, § 4, pp. 9, 13, 15), nevertheless appeared distinctly important for a compositor, and it therefore seemed worth while to investigate whether this were so or not.† This leads to a consideration of the results obtained at PWC.

As was indicated above (pp. 19–20) a certain amount of specialisation had been introduced into composing at PWC. Case-room work was here divided into four parts—display, making-up, correcting, and stone work. Eight compositors were tested who were engaged on display almost entirely, thirteen who were engaged on making-up, thirteen on correcting, and

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* The compositors were not asked their ages, but they were asked how many years they had been engaged on case-room work. The age of a compositor could thus be approximately determined by adding 14 to the number of years given by him as the time he had spent composing (since apprenticeship normally begins about the age of 14). At PWA the average number of years experience for the 25 compositors was, approximately, 21 (the *M.V.* being large, namely, 13). At PWB the average for the 24 compositors was 18 (with an *M.V.* of 9)

Efficiency in composing was not dependent, in the groups tested, upon amount of experience of composing, for the correlation coefficients of composing efficiency with experience of composing (number of years in the case room) were so low as to be insignificant at both works, while at one the coefficient was positive and at the other negative. These coefficients were, at PWA, $-\cdot 30$ (*p.e.* $= \cdot 13$), and at PWB, $+\cdot 28$ (*p.e.* $= \cdot 14$). Again, efficiency in the tests was not to any extent dependent on age, as the coefficients of test efficiency and age were, at PWA, $-\cdot 47$ (*p e.* $= \cdot 11$), and at PWB, $+\cdot 09$. hat is, at PWB age appears to have had no effect either upon the test performances or upon composing efficiency. At PWA there is some tendency for increasing age to affect the test performances (and possibly composing efficiency also) detrimentally. The correlation of the tests with composing efficiency is, however, brought about here to only a negligible extent by age, as the partial coefficient of the tests with composing efficiency (age being excluded) is $+\cdot 68$ instead of $+\cdot 71$, which it was before the effects of age were eliminated.

In this note, "efficiency in the tests" means efficiency in the three tests finally adopted as valuable.

† Strictly, the investigations described below *could not* establish this. For the partial coefficient of the Immediate Memory test used in them was not obtained (cancellation, match stick insertion, and directions being excluded). Here, however, it seems possible to argue from the nature of the tests: that is, we may infer that the capacities required for the Immediate Memory test were largely different from those required for cancellation, match stick insertion, and directions; this inference being based upon a comparison of the tests. It is admitted, however, that such inferences are generally unsafe.

six on stone work. It is of course doubtful how far any particular compositor was specially adapted to the particular sort of case-room work on which he was engaged. The overseer had to some extent tried the compositors at different types of work and believed that he had been able to sort them out fairly well according to their aptitudes; but it is possible that he was not altogether successful, for such a problem is always difficult. However, to these four groups several tests were given including the test described above (§ 4) for "immediate memory span."

The results for most of these tests yielded nothing new, and therefore need not be discussed. The results obtained with the "immediate memory span" test were briefly as follows: the correlation coefficient between efficiency in this test and efficiency in *display* work was + ·64 (*p.e.* = ·11). With the other groups of workers (those engaged on making-up, correcting, and stone work) the corresponding coefficients were all negligible (in one case *positive*, in the other two *negative*; in all three cases *small*). Although the smallness of the display group (eight men only) renders it impossible to place much reliance upon the coefficient of + ·64, the result suggests that, in the actual work of setting up type, immediate memory span is of some importance. This suggestion is strengthened somewhat by considering the average scores obtained in this test by the four groups. These are set out in TABLE IV.

TABLE IV.

Scores in immediate memory span test obtained at PWC by groups of compositors engaged on different sorts of case-room work.

Nature of Work.	No. of Comps.	Average Score in Test. (Av. No. of Words per Sentence).	Standard Deviation.
Display - -	8	12·3	2·1
Making Up -	13	11·5	2·0
Correcting -	13	11·1	2·7
Stone - -	6	10·6	2·2

The results given in TABLE IV. show a somewhat larger average immediate memory span for the display group than for any other, while the smallest average span is shown by the stone-work group. And analysis of the work of the different groups seems to show that the actual setting up of type (involved in the work of the *display* group, but not in the work of the other three groups) requires immediate memory span more than any other part of composing, while it is even clearer that stone work requires this capacity least. But as a matter of fact the differences in the average "spans" between the four groups are so small as to be statistically non-significant; they

may all be due to chance. Taking them in connection with the character of the coefficients between the present test and the work of the different groups, however, the suggestion of the importance of immediate memory span for composing seems strengthened.

The results obtained at PWD may be referred to briefly. The eleven compositors tested here were all women, and it was impossible to get them graded for efficiency as compositors except in two groups, one containing five compositors and the other six.

Correlation coefficients obtained with such small numbers as these are unreliable, and will not therefore be given in detail. But it may be said that the results tended to confirm those obtained at the other three works. In general, the coefficients were "large,"—that is, generally speaking, the inefficient compositors did badly in the tests and the efficient compositors did well. For instance, with the group of six, the coefficient for immediate memory span and composing was $+ \cdot 71$, for the directions test and composing it was $+ \cdot 82$, and for the match stick insertion test and composing it was $+ \cdot 65$; while in the other group the directions test yielded a coefficient with composing of $+ \cdot 90$ and the cancellation test a coefficient of $+ \cdot 65$. Such results would of course mean practically nothing if they stood alone, but give some confirmation of the results obtained with larger groups at the other three works.

§ 6.—Suggested Conclusions concerning the Capacities required by the Hand Compositor.*

The compositor seems to require first of all good eyesight, and secondly, physical strength somewhat above the average (though if specialisation such as that described as in operation at PWC were to become common, only "stone" workers would require such physical strength). To these two capacities the following four may be added, on the basis of the results given in this report :—

(*a*) Right hand and arm dexterity;
(*b*) Rapidity of visual observation;
(*c*) A large immediate memory span;
(*d*) A certain degree of "general intelligence," though these investigations allow of no judgment as to what this degree is, relative to the degree required by other occupations.

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* The only investigations known to the writer dealing with the capacities required by a hand compositor are German, namely: (1) *Der Berufseignung der Schriftsetzer*, by O. Lipmann; and (2) *Eignungsprufungen bei der Einfuhrung von weibliche Ersatzkräften in das Stuttgarter Buchdruckgewerbe*, by D. Krais. Both are published by Barth, Leipzig (1918). They have been briefly summarised in the Fatigue Research Board's Report, No. 12, pp. 31–33, entitled *Vocational Guidance* (a review of the literature), 1921.

It is believed also that the capacity to estimate size and form is important, though further investigation upon this point is required.

§ 7.—Tests on Readers and Monotype Key-Board Operators

In addition to the hand compositors. about 27 readers and 30 monotype key-board* operators (practically all those engaged on these two types of work at PWA. PWB, and PWC) were given various tests. As the method pursued here was similar to that adopted for (hand) compositors, it will not be described in detail.

Partly because of the small number tested at any one works, the results are chiefly of value because of the suggestions to which they give rise. The difficulty of obtaining accurate efficiency gradings was in general greater here than with the (hand) compositors. This was not due to the special nature of the readers' and key-board operators' work (the latter indeed, lending itself to precise measurement rather more easily than that of the hand compositors) but to special conditions in the various printing establishments in which the tests were made. For instance, at two establishments the monotype operators were in very different stages of training, and scarcely one of them was fully trained. It was consequently impossible to get any grading for their relative efficiencies as key-board operators, which did not merely express the fact that they had had unequal practice at the work. At the third works, however, five fully trained operators were tested, and the relative efficiencies of these men in "ens" per hour were known precisely.† The grading of these five men, indeed, was the most satisfactory *work* grading obtained in these investigations. It was facilitated by the fact that they were paid on a piece-rate bonus system, and were pretty clearly working up to maximum capacity. The grading of the *readers* at this establishment was unsatisfactory, partly because they had had different amounts of experience of the work. At another establishment, however, a fairly good grading of 12 readers was obtained. It therefore seemed that the most valuable suggestions would be obtained from the results of the tests on these 12 readers and the five key-board operators just mentioned.

(*a*) The readers were tested for rapidity of observation, for immediate memory span, and for "intelligence" (several tests).

* The monotype is a modern composing machine. Operating it is, in principle, much the same as operating a typewriter. Indeed, one arrangement of keys on the monotype is that of the universal typewriter keyboard. The monotype machine is, of course, vastly more complicated than a typewriter; the only similarity is the keyboard method of operation.

† An "en" is a unit of measurement in composition. It represents so much distance along a line of type.

It may be of some interest to state that the best of these five operators averaged about 14,000 ens per hour, that three averaged about 11,000 each, and that the fifth averaged about 8,500.

These all gave significant positive correlations with efficiency as readers. The total performance in the various tests used correlated + ·71 with reading efficiency.

(*b*) The key-board operators were tested for rapidity of observation, immediate memory span, "intelligence," and "finger co-ordination" (by pressing each of three keys in succession as rapidly as possible). The average ranking in all these tests was practically indentical with the overseer's grading for work efficiency, the correlation coefficient being + ·90.

The results obtained with these readers and monotype key-board operators suggest the importance of rapidity of observation, immediate memory span, and "intelligence" for reading and key-board operating as well as for hand composition. It might seem that the key-board operators require in addition certain finger dexterity; but while this is possibly so, a proper training in the use of the hands in operating is probably more important than any such endowment. The results are, in general, too inadequate to be given in detail, and the various suggestions derived from them require verification.

§ 8. Application of Results.

Knowledge of the psycho-physiological capacities required by a compositor would most naturally be applied to the printing industry in choosing apprentices. This important task is at present performed on very inadequate data. A boy's fitness for printing is determined by the standard he has reached in the elementary school, by his appearance and manner, and sometimes by the results of unstandardized tests in writing, reading, spelling and grammar, given him by the works manager or case-room superintendent. In addition, a trial period in the case room is often insisted upon before a lad is formally accepted as an apprentice. This whole procedure is generally recognised by the printing trade as unsatisfactory. Southward writes: "This is owned as one of the principal evils in the printing trade—the fact that so many boys are apprenticed who are totally unfit for it. They are deficient in mental and physical qualifications."* He is emphatic that "great caution should be exercised in the selection of an apprentice . . . An apprentice should never be chosen until after at least a month's actual trial of the business."† But the fact is that a works manager, however "cautious" he may be, neglects to determine to what extent a boy is *naturally fitted* for a printer. This is at present inevitable, as he has not been provided with any means of doing so. His examination of a boy consists in testing roughly certain *acquisitions*—spelling, grammar, &c., and while these are important, natural endowments are, at the apprentice stage, more important. The present more or less rough methods

* *Modern Printing* (1915 ed.), Vol. II., p. 335.
† *Ibid*, p. 331.

of testing knowledge (and character) might, therefore, with advantage to the industry, be supplemented by an exact method of determining aptitudes. This would involve the use of tests more or less similar to those employed in the investigations reported in Section IV. But to give a prospective apprentice such tests is in itself of no value, since at present there is nothing with which to compare his performance; it is of no value to know that a particular boy of 14 can put 15 match sticks into holes in 30 seconds (in the *Match Stick Insertion test*), unless it is also known what records other boys of 14 can make in this test. What is needed is a knowledge of the average performance of boys of 14 in all the relevant tests, together with the range of deviation above and below these averages. The results of investigations yielding this knowledge would be most usefully arranged in percentile tables, which would permit a ready and exact comparison between the performance of any given boy in a particular test and the performances of other boys of his age. We should be able to say, for instance, that such-and-such a boy was above or below the average in such-and-such a test, and precisely how far above or below. And we might decide that only those boys who reached an average percentile grade of 60 in the relevant tests should be advised to become printing apprentices.* Such a procedure should enable those who now constitute the Grade III. compositors to escape an occupation their native incompetence for which must bar the way to success with ill effects to themselves. What is required is (1) certainty as to the capacities required in the printing trade; (2) investigations to obtain percentile tables of the kind outlined. The further work thus suggested is as follows:—

(*a*) Where facilities offer, other investigations of the type described in this report should be carried out (not necessarily with the same tests).

(*b*) Certain tests, including those that gave significant positive correlations in the present investigations, should be given to a fairly large group of boys of the age at which boys become apprentices to the printing trade. This would yield the percentile tables.

(*c*) The tests should then be given to large numbers of boys just entering on apprenticeship. If possible, these boys should be retested annually, to determine what sort of changes in the capacities to perform the tests were made by their work as compositors. For instance, if from one year to the next a vast improvement occurred in a given test, one might infer that the capacity exercised by the performance of that test was actually in constant use in the compositor's work.

Along with the giving of the tests, as complete and accurate a record as possible should be obtained of the efficiency of the

* This would mean that suitable boys would be among the top 40 per cent. in their capacity for the tests.

boys in their work. The results thus obtained should, in a few years, provide a thoroughly sound basis for vocational guidance in the printing trade. The work would naturally be carried out in close connection with technical schools of printing.

APPENDIX I.—FACTORS WHICH INFLUENCE COMPOSING EFFICIENCY.

Efficiency in composing is dependent upon at least four kinds of factors namely:—

(1) Trade knowledge and experience;
(2) Specific psycho-physiological capacities;
(3) General health;
(4) "Moral" qualities, such as "application" or "ambition."

The importance of the first of these may be judged from the length of the compositor's apprenticeship—seven years. This period is undoubtedly too long; but several years are necessary for the apprentice to acquire the knowledge of the thousand and one things that must be known by the expeditious compositor. A man may be perfectly endowed with the psycho-physiological qualities required for composing, and possess good general health and "application"; but he will not be efficient as a compositor until he acquires a considerable amount of trade knowledge.*

It is important to recognise, on the one hand, that a compositor *may* become fairly efficient without any *special* endowment of the qualities required for his occupation. When this happens, trade knowledge and moral qualities (if general health is fairly robust) compensate for a certain lack of these qualities. On the other hand, a compositor may be relatively inefficient, not because he is lacking in these qualities, but because he lacks trade knowledge or health or "character." Lack of trade knowledge would appear to be not so uncommon as might be expected. This is sometimes due to the master printer not giving the apprentice a satisfactory opportunity of acquiring it. At the present time it is, perhaps, most often due to a lack of desire on the part of the apprentice to acquire the knowledge.

The point to be emphasised is that composing efficiency does not depend simply upon the possession by the compositor of certain psycho-physiological capacities. This has to be borne in mind when considering the correlation coefficients given above (§ 5). Efficiency in the tests that were used was presumably determined (primarily) by the special capacities required for the tests, and not by extraneous factors. If efficiency in composing were similarly determined—that is, by the special capacities required for composing—we should expect, in so far as the tests were relevant, an almost perfect correlation between efficiency in

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* This may be illustrated by reference to the movements of the left hand during composition. The left hand holds the composing stick in which the letters are placed with the right hand. Now a compositor sometimes keeps his left hand in the one position (near his body) while composing, and makes his right hand travel *to this position* with every letter, no matter how distant is the letter's box. Compositors who have been well taught, however, make the left hand follow the right as it moves about the case, and consequently shorten very considerably the distance over which the right hand must travel. This method is often not used by compositors because they are ignorant of it: yet it, in itself, will probably increase a compositor's rate *at least* 10 per cent. This may be inferred from the fact that the average number of match sticks inserted by the compositors (in carrying out the Match Stick Insertion Test) when the box was placed at a distance of 22 inches from the holes was 16, whereas when it was placed at 6 inches distance the average number was 19.

the tests and efficiency in composing. The correlation obtained was not perfect, which is as it should be, seeing that factors enter into efficiency in composing which do not enter into efficiency in the tests (*e.g.*, trade knowledge and experience). Indeed, when it is realised how large a part in a compositor's efficiency is played by trade knowledge alone, it may seem surprising that the correlation coefficients are as high as they are. In the circumstances, their size seems to indicate that the functions brought into operation in the performance of the tests are distinctly important for composing efficiency.

Appendix II.—The Industrial Grading of the Compositors by Efficiency in their Work.

The actual efficiency grading of the compositors by their overseers and works managers was based upon considerable experience of their output —in no case less than three months. Assuming that relative efficiency was accurately estimated, there is, of course, the difficulty, so far as this investigation is concerned, that it is a resultant of several factors. The grading was not based simply upon the psycho-physiological qualities required for composing. The compositor placed first at one works was given this position primarily because of his industry and reliability (although he was a fairly expeditious compositor). If a job were given to him, the overseer knew that it would be done perfectly. It seemed that certain other compositors were placed high chiefly because of sheer composing ability, especially when, as in one case, the compositor's "industry" was graded "Class III." A compositor who was not "industrious" could only be placed among the most efficient workers if he were highly endowed with the capacities required for his work. In general, however, it seemed clear that "moral" qualities had a considerable influence on the efficiency grading.

But the efficiency grading itself—neglecting now the question what factors *conduce* to efficiency—was not entirely satisfactory. A compositor's rating was based upon his relative output. Composing output, however, is not amenable to absolutely accurate measurement. This is especially true of all jobbing or display work. Hence, although the gradings were made with the utmost care. the possibility of errors of judgment, from various causes, in the ranking of the compositors, must be reckoned with.

Further, one works manager was very emphatic that the grading given by his case-room overseer and himself must not be taken too rigidly. He insisted that it was an efficiency grading for the particular sort of work of his firm, and that his compositors would be graded in efficiency somewhat differently by other overseers if they were placed in other works. To some extent this was obvious. A compositor could easily rank high for "monotype make-up," "solid" work involving little taste or judgment, and very low for display work. But it was thought by this works manager that different overseers might grade the same man differently even for a similar type of work. In view of this difficulty, every effort was made to get an efficiency grading which would not express merely the conditions of a particular works It was, however, impossible to obtain a perfectly satisfactory "absolute" grading of this kind, and in these circumstances it seems necessary to make the same tests in a number of different works. Tests which *generally* yield significant positive correlation coefficients might reasonably be taken as indicative of the capacities required for composing.

It should be added that the grading at PWB was probably rather more reliable than at PWA, owing to the fact that at PWB there frequently occurred intense rushes of work, which gave good opportunity for determining the relative efficiencies of the compositors. This should be

remembered in connection with the fact that rather higher correlations were obtained at PWB than at PWA (*see* p. 25).

This Appendix has been added for the purpose of emphasizing a general difficulty in investigations of the type here reported; a difficulty so great as sometimes to render such investigations almost impossible. For these investigations, so far as they proceed by a correlation method (whether in a refined or rough form) involve the assumption that an efficiency-for-work grading made by an overseer is indicative of the relative degrees of the capacities required for that work, possessed by the workmen who are graded. But such a grading may be affected by many other factors besides the capacities called into operation by the work, *e.g.*, by the varying experience of the men in the work, by their "temperaments," by their relations with their foreman or fellow-workers, by their domestic relationships, by the foreman's intelligence and judgment, and so on. An investigator soon becomes aware of such interfering factors, and naturally tries to eliminate them as far as possible; but the task is difficult. It may easily happen that a group of workers to whom capacity tests *could* be given (both themselves and the management being willing) are unsuitable material for investigation owing to various unfavourable conditions

So far as further research upon vocational test problems is concerned, it is suggested that time spent in obtaining suitable conditions for giving tests—that is, conditions in which interfering factors are at a minimum—will be well repaid, and that it is *useless* to attempt to correlate efficiency in any work with efficiency in any test without the greatest caution. Every effort should be made to find out *what is the precise basis of the overseer's efficiency grading for work in the case of every man,* and the investigator should be prepared to find that this grading is sometimes partly determined by factors irrelevant to the capacities required for the work.

B.—THE MEASUREMENT OF PHYSICAL STRENGTH WITH REFERENCE TO VOCATIONAL GUIDANCE

by

B. Muscio, M.A. (assisted by A. B. B. Eyre.*)

§1. Purpose of the Investigation.

The investigation here reported was intended to form an initial step in vocational guidance research.

The more completely a man is adapted to his work by the possession of the mental and physiological capacities it calls into play, the less is he likely to develop injurious industrial fatigue. While this seems true, whatever the nature of the work or of the psycho-physiological capacities required for it, it seems especially true as regards occupations that make heavy demands on physical strength. In the present state of industry, certain occupations make demands upon strength so great that only those who are stronger than the average should be allowed to engage in them. Thus, considerable strength is demanded in various classes of transport work; in certain mining and building operations; in certain engineering processes, such as moulding and rivetting; in various occupations in the cement and pottery industries, &c. In all such occupations, inadequate physical strength cannot but result in undue fatigue or relative inefficiency, or in both. Nevertheless, no adequate scientific attempt has yet been made to determine the degree of strength required for different occupations. Vocational guidance has here, therefore, an obvious and definite problem.

Investigations attempting to solve this problem fall naturally into two classes. On the one hand, it is necessary to obtain a satisfactory method for the measurement of physical strength and to determine by this method the range of strength with regard to those among whom vocational guidance would operate; and, on the other hand, it is necessary to establish the minimum standards of strength required for different occupations. The present investigation attempted to contribute something to the former of these two questions.

§ 2. The Measurement of Strength.

The methods of measuring strength most frequently used in the past are as a rule considered unsatisfactory. The best known

* Mr. H. G. Holt assisted in the early part of the investigation, and when he left the service of the Board his place was taken by Mr. Eyre.

is that which took as an indication of general strength the strength of the hand grip. Some form of hand dynamometer was used to measure the grip, the most usual form being an elliptical spring upon which the "subject"—the person being tested—exerted pressure by flexion of the hand. Strength was registered as so many lbs. or kgms.

One of the two chief objections to this method of strength measurement is that the older form of dynamometer does not allow equally good leverage for hands of different sizes, with the result that two persons of the same strength might be rated by it as of different strength if the hands of one were longer than those of the other. This objection does not apply to the Smedley hand dynamometer, which is adjustable to the size of the hand.

The other important objection to the grip method is that it infers total muscular strength from the strength of a relatively small part of the total musculature. It has been urged that in specific cases the grip, relative to the total musculature, may be either comparatively weak or comparatively strong, and that, in consequence, an erroneous idea of total muscular strength might often result, if an estimate of total muscular strength were based upon strength of grip. Within the last few years, Dr. E. G. Martin has invented a method of testing strength to which this objection does not apply.*

The test has obtained a considerable reputation in the United States. It has been used in fatigue investigations, and is recom mended for industrial use by Dr. R. A. Spaeth, who writes:

> "Nearly all the older and familiar forms of dynamometers are either theoretically unsound or fail to give the desired information. Dr. E. G. Martin's spring balance technique has, however, met both of these objections in a most satisfactory fashion. Not only is the routine of Martin's test extremely simple, but it has the additional

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* The Martin method of strength measurement has been described, and results obtained with it have been presented in the following articles:—

(1) Martin, E. G., and Lovett, R. W.—A method of testing muscular strength in infantile paralysis: *J. Am. M. Ass.*, 1915, *65*, 1512.

(2) Lovett, R. W., and Martin, E. G.—Certain aspects of infantile paralysis, with a description of a method of muscle testing: *J. Am. M. Ass.*, 1916, *66*, 729–733.

(3) Lovett, R. W., and Martin, E.G.—The spring balance muscle test: *Am. J. Orthop. Surg.*, 1916, *14*, 415–424.

(4) Mosher, C. D., and Martin, E. G.—The muscular strength of college women with some consideration of its distribution: *J. M. Ass.*, 1918, *70*, 140–142.

(5) Martin, E. G.—Muscular strength and muscular symmetry in human beings; I., In children: *Am. J. Physiol.*, 1918, *46*. 67–83.

(6) Martin, E. G., and Rich, W. H.—Muscular strength and muscular symmetry in human beings; II., In adult males: *Am. J. Physiol.*, 1918, *47*, 29–42.

advantage of involving an inexpensive and easily procurable piece of apparatus. We have found that two intelligent workmen can, with a very little practice, be taught to carry out Martin's test with speed and accuracy." *J. Industrial Hygiene*, 1920, *1*, 441.

The Martin method does not test strength of grip. The apparatus used is a self-registering spring balance, which has a strong handle at one end, and a leather loop $1\frac{1}{4}$ in. wide and 30 in. in circumference attached to the spring at the other. Compared with the grip method, the Martin method has two special features. First, the strength of a number of muscle groups is tested. Secondly, the subject exerts strength by *resisting* a pull: the leather loop is placed over an appropriate part of a limb and the subject resists a pull made rapidly by the experimenter, the resistance being measured in lbs. The limb or other part of the body over which the loop is placed must occupy a standard position for the testing of any given muscle group, and the pulling must be made in a standard manner.

Martin began by testing over 40 muscle groups, and he took the sum of the strengths of these (each recorded in lbs.) as the measure of an individual's total muscular strength. But testing over 40 muscle groups occupied considerable time, and, compared with the grip method, this method of measuring strength thus seemed to have lost as much in convenience as it gained in reliability. Martin found, however, that it could be very much shortened with little effect on its reliability. His short method* consists in the testing of eight muscles: the two pectorals, the two forearm flexors, the two thigh abductors and the two thigh adductors. These muscles were selected chiefly because the strength of each correlated very highly (above $+\cdot 80$) with entire strength, of which their combined strength† could therefore be considered a reliable indication.

In view of various objections to the grip method of measuring strength, and of various considerations seeming to favour the Martin method, the investigation here reported started from the presupposition that the Martin method would probably be entirely satisfactory as a means of determining relative strength. His short method was therefore used with the whole of the

* The Pearson correlation coefficient of the short with the full test for 56 adults was found to be $+\cdot 94$ (*p.e.* $= \cdot 01$): Martin and Rich. *Am. J. Physiol.*, 1918, *47*, 33.

† Martin found that the sum of the strengths of these eight muscles was approximately 15 per cent. of the sum of the strengths of *all* the measurable muscle groups. He then multiplied the sum of the strengths of the eight muscles by $6\cdot 67$ (the reciprocal of $0\cdot 15$) when comparing different persons. This is entirely unnecessary, since the final figures give only a *relative* measure of strength in any case, and this can be obtained from the sum of the strengths of the eight muscles simply. *cf.* p. 35 of the article numbered (6) in footnote to p. 39.

subjects.* But, in addition, nearly all† the subjects were tested with the Smedley hand dynamometer, as it seemed that it would be valuable to compare the results of the two methods.

§ 3. The Subjects Examined.

The subjects of the investigations were over 2,300 youths ranging in age from 13 to 20. Of these about 1,500 belonged to industrial Essex and the remaining 800 to Manchester. More than half the Essex youths were either day or evening pupils at the Technical Institutes at Colchester, Leyton, and Walthamstow, the remainder being employed chiefly in engineering industries. About 200 were employed in the cement industry. The Manchester youths were part-time pupils at the Engineering Technical Schools connected with the Crossley Lads' Club, Ashton Old Road, Openshaw. The large majority of the subjects (Essex and Manchester) were receiving whole or part time training in engineering work, and those receiving part time training were employed by engineering firms. The subjects may therefore be taken as a fair sample of those of whom industry will often demand considerable physical strength.

§ 4. Specific Nature of the Investigation.

The primary aim of the investigation was to obtain exact data as to the range of strength among adolescent males by means of some reliable method of strength measurement. The data obtained were the following :—

(1) Strength, by the Martin short test method.
(2) Strength of hand grip, as measured by the Smedley dynamometer.
(3) Weight, without shoes.
(4) Standing height, without shoes. (Standing height was not taken at Colchester or Walthamstow Technical Institutes, *i.e.*, in the early part of the investigation).

Weight and standing height were taken as it was thought that they might throw some light on the main problem. No explanations are necessary concerning the procedure in taking these two measurements; but the methods of testing strength must be described in detail.

(a) *The Martin Strength Test.*

The Martin short test requires a self-registering spring balance, with a scale-capacity of about 200 lbs., and a strong table. The table used was 6½ ft. by 3 ft. It was provided with two firm upright posts, 3 in. square and 6 ft. in height, which were secured to the two legs at one end of it.

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* The Industrial Fatigue Research Board is indebted to Dr. Martin, through Professor F. S. Lee, for the spring balance used in this investigation.

† All subjects would have been given this test, but for the fact that the dynamometer did not arrive until a short time after the investigation had begun

Two persons are necessary for the carrying out of the test; the *operator*, who does the pulling, and an *assistant*, who adjusts the leather loop of the balance on the subject's limb. When the loop is adjusted, the operator says "pull" and then develops tension as rapidly as possible without jerking until the subject's resistance is overcome.* The scale is then read and the sliding indicator pushed back to zero, the apparatus being then ready for another pull. In the present investigation, each muscle group was tested three times in succession, as it soon became evident that, during the first pull, at least, certain subjects did not realise clearly what was expected of them, and consequently gave relatively poor results. This happened in spite of the fact that most of the subjects saw at least one other subject tested before being tested themselves. The greatest of the three resistances of a muscle was taken as the measure of its strength.

The procedure† for testing each muscle included in the short test is as follows, the subject being fully dressed with the exception of his coat.

Pectorals.—The subject stands at attention with the middle of his back pressed firmly against one or other of the two upright posts fixed to the table, while the hand of the arm not being tested grasps a piece of knotted rope fastened to the table behind him. The assistant stands in front of the subject, facing him; places the loop of the balance over the arm just above the elbow; holds the loop with one hand and the subject's hand or wrist with the other. Keeping the subject's arm straight, he draws it across the subject's body as far as possible. At the command "pull," the subject is required to prevent his arm from being drawn backward and downward, while the operator, standing at his side, pulls against the resistance in such a way that, as the arm is drawn back, it passes clear of the body.‡ The arm should be drawn back until it reaches a vertical position.

Forearm Flexors.—The subject lies on his back on the table, his head resting on a cushion, and his feet in a support. The assistant stands at the subject's side. With one hand he holds the elbow to the table, and with the other brings the subject's forearm into a position of flexion about 15° toward the shoulder from the vertical, and adjusts the loop to the wrist so that its

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* Martin required the *assistant* to give the signal for resistance, and also a further signal to cease resisting once the resistance had been overcome. The latter part of the procedure is practically impossible to carry out, and is also unnecessary; hence it was discarded. It was found more convenient, also, for the operator to give the signal for resistance. Martin used the signal "hold back" instead of "pull," but the advantages of a monosyllabic signal are obvious.

† This description is taken almost verbatim from Martin and Rich. "Muscular Strength and Muscular Symmetry in Human Beings," *Am. J. Physiol.*, 1918, *47*, 34–36.

‡ This part of the procedure is difficult to carry out satisfactorily, as subjects almost invariably try to increase their resistance by pressing the arm against the body.

upper edge is at the crease of the skin at the base of the hand. The operator stands at the foot of the table, and upon giving the signal to the subject to resist, pulls the forearm into a vertical position against the subject's resistance.

Thigh Adductors.—The subject lies on his back on the table with the foot of the leg not being tested in the support, and steadies himself by grasping the table. The assistant stands at the foot of the table, raises the subject's leg by the heel with one hand until it is just above the toe of the other leg, and draws it into extreme adduction. The loop is placed in such a position that it will just clear the top of an ordinary shoe. The foot of the leg being tested is kept vertical. The operator stands at the side of the table and develops tension upon giving the signal to resist. The leg is drawn into line with the axis of the body.

Abductors.—The positions of the subject, the operator, and the assistant are the same as for the adductors. The loop is placed as for the adductors except that the direction of the pull is opposite. The leg to be tested is drawn 15° beyond the line of the axis of the body, and the subject's task is to resist the operator's attempt to pull it back to this line.

The muscles were tested in the following order: right pectoral, left pectoral, right forearm flexor, left forearm flexor, right thigh abductor, left thigh adductor, left thigh abductor, right thigh adductor.

All readings were taken to the nearest lb.

(b) *The Smedley Dynamometer Grip Test.*

In measuring the strength of grip with the Smedley dynamometer,* the instrument is first adjusted to the size of the hand by lengthening or shortening the distance betseen the bars gripped by the subject. Six grips are then taken, with the right and left hand alternately, and the largest pull with either hand is considered the measure of its strength. As the instrument is self-registering, tension may be released as soon as the maximum point in the pull has been reached. A steady pull is insisted on. The dynamometer must be held in some standard position if different individuals are to be compared, and in this investigation it was allowed to rest face upwards on a table while the pull was made. By watching the movement of the registering pointer the subject could thus get some idea of the efficiency of his grip and was spontaneously stimulated to put forth his best efforts.

Readings were taken to the nearest half kilogram.

§ 5. Treatment of Data.

In working up the data, the subjects were divided into half-year age groups, the youngest such group consisting of youths from 13 to 13½, the next youngest of youths from 13½ to 14,

* This instrument may be obtained from Messrs. Stoelting & Co., Chicago. The price is about $40.

and so on. In distinguishing between successive half-years, the following plan was adopted. From the birthday month to the fifth month afterwards, both inclusive, was considered one half-yearly period, and from the sixth to the eleventh months, both inclusive, after the birthday month was considered a half-yearly period. For such half-yearly periods, results are given below for hand grip (average of right and left hands) and weight. Results obtained with the Martin test are not given in detail, because this test proved to be unsatisfactory, as will be shown. The data for standing height are not given in detail because, as will be explained, it did not seem possible to make any use of them. The results are presented in the form of percentiles for each half-year group (Appendix I.).

§ 6. The Martin Test Results.

The function of operator in carrying out the test was performed by two persons (one at one time and another at another time) who will be referred to as operators E and H respectively. H was responsible for operating in the case of about 850 Essex youths and 150 Manchester youths, while E was operator for the remainder—about 650 Essex youths and 650 Manchester youths. Both operators performed their work with the greatest care, and with the original Martin instructions before them. E worked for several days in conjunction with H before taking over the operating from him. In my opinion, the test was made throughout as carefully as it would ever be made if used extensively, and with much more care and intelligence than would generally be used if it were widely adopted. Three assistants took part in the work, each helping in about one-third of the total number of tests.

After about half of the Essex youths and the whole of the Manchester youths had been tested, the results thus far obtained were provisionally worked up. (All these Essex youths were tested by H, and the Manchester youths partly by H and partly by E.) *The fact was then realised that operator E had been consistently obtaining larger resistances from similar subjects than operator H.* (This statement is based on the Manchester data.)

It might theoretically have been the case that E's subjects were superior physically to those of H; but the reverse seems to have been true. As regards height, E's subjects were taller than those of H in only one age group, in all the others H's subjects being the taller; and there was an *average* difference per age group of about three-quarters of an inch in favour of H's subjects. In regard to grip and weight, which, as will be shown below (§ 8), correlate highly with general strength as measured by the Martin test, H's subjects averaged per age group approximately $2\frac{1}{2}$ lbs. heavier than E's and half a kilogram stronger in grip. Hence, we may be pretty confident that E's subjects were really *weaker generally* than those of H; while by

the Martin test they are shown to be consistently stronger. The relevant results are presented in Table I, which gives average strengths for six age groups obtained by the two operators. (All the youths of these groups belonged to the same locality *in Manchester*, and were in attendance at the same Technical Institute.) The age groups not included in this table contained too few subjects in the case of one or other operator to allow of a valid comparison between them.

Table I.—Showing the different results obtained from similar subjects by two operators with the Martin short test.

(The unbracketed figures in the columns headed "average strength" are the sums of the strengths in lbs. of the muscles tested. The figures enclosed in brackets are the standard deviations* in lbs.)

Age.	H's results (Manchester Subjects).		E's results (Manchester Subjects).		Difference between the results, expressed as percentage of H's results.
	No. of Subjects.	Average Strength (and *s.d.*)	No. of Subjects.	Average Strength (and *s.d.*).	
14½—15	26	325 (55·09)	76	360 (69·57)	10·77
15 —15½	20	342 (46·45)	74	387 (81·25)	13·16
15½—16	34	373 (63·56)	68	421 (93·48)	12·87
16 —16½	28	389 (65·52)	73	442 (103·5)	13·62
16½—17	17	409 (60·36)	87	485 (111·0)	18·58
17 —17½	19	440 (75·72)	74	527 (125·0)	19·77

Thus in every age group E's results were definitely greater than those of H, and in the last two age groups for which a valid comparison was possible the results obtained by E were nearly 20 per cent. greater than those obtained by H. (It should be added that the assistant was the same for both operators so far as these results are concerned.) Such a difference in results would appear to have been unanticipated by Martin. It constitutes a serious criticism of the test.

If two careful operators can obtain very different results with the test, its reliability for numerous purposes is very small; and it will always be impossible to determine the significance of strength differences shown by it *when the operators are different.*

* The "standard deviation" indicates the degree to which any given values deviate from their mean (or average). Its formula is:

$$s.d. = \sqrt{\frac{s(d^2)}{n}},$$

where n = the number of values concerned, and $s(d^2)$ = the sum of the squares of the individual deviations from the mean of all the values.

In the present case, the natural suggestion was that the cause of the difference was a difference in the physique of the operators, E being the stronger operator, and in general rather bigger physically than H. Whatever the precise cause, the fact is that differences in operating, *too subtle to be observed*, produced a considerable difference in results. It would be psychologically interesting if it were established that, within limits, the more vigorous the pull of the operator the greater the subject's resistance. This is not the only possible explanation of the facts. The different results may have been due to general differences in the personalities of the operators.

The situation was further complicated, however, by other conditions. After a thorough reconsideration of the whole test procedure, an almost slavish attempt was made to follow Martin's directions with the remaining 650 Essex subjects. The method now adopted by E was, however, not observably different from his method in Manchester. To appreciate the results, the following facts must be noted.

The data obtained in the investigation with regard to grip, standing height, and weight, showed clearly that the Essex subjects were physically superior to the Manchester subjects (for details *see* below, *Tables IX*, *X*, and *XI*, and *Figures* 3, 4, 5, and 6). It was therefore expected that the Martin test would show a similar difference between these two main groups of subjects. For the purpose of comparing the results, it is fairest to consider the Essex subjects tested at the Walthamstow and Technical Institutes only, as these subjects were as nearly identical with the Manchester subjects as any that could be obtained. H operated for the Walthamstow and E for the Leyton subjects. The data obtained showed that the Walthamstow and Leyton subjects were of roughly equal* weight and strength of grip (standing height was taken at Leyton but not at Walthamstow), and that in these respects they were superior to the Manchester subjects (*cf.* below, *Tables IX*, *X*, and *XI*, and *Figures* 3, 4, 5, and 6).

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* The results for Leyton and Walthamstow are not perfectly regular, as is to be expected in view of the numbers of the subjects: between the ages of 15 and 18 there were more than double the number of subjects at Manchester than at Leyton and Walthamstow together. On the whole, it would seem that the Leyton subjects were slightly heavier (and had a slightly stronger hand grip) than the Walthamstow subjects (Fig. 4). For the older age groups, however, the Walthamstow subjects are the heavier (and the stronger in grip). Also, for the youngest age group of all (not shown in Figs. 3, 4 and 5 because of the small number of subjects in this group for Manchester), the Walthamstow subjects are again superior to the Leyton subjects. In hand grip, for instance, these Walthamstow subjects show an average of 27·4 kgms, while the Leyton subjects show an average of only 24·44 kgms. Hence, the Walthamstow and Leyton subjects exhibit no *consistent* difference, in some age groups Leyton being superior, and in others Walthamstow; and it may therefore be assumed that with larger numbers the results for the two places would be more nearly identical for all age groups. Both these places, however, are *consistently* superior to Manchester both in weight and grip

As regards the Martin test results, however, the two operators obtained divergent results. On the whole, H's Essex subjects (as was anticipated in view of the results for grip, weight and height referred to in the preceding paragraph) shewed themselves *stronger* by the Martin Test than his Manchester subjects, though his Essex results are not very regular, and in two age groups they are lower than those for the corresponding age groups of his Manchester subjects. But the Essex subjects tested by E were shewn by the Martin test to be *actually weaker* than E's own Manchester subjects (*see Table II*) and even slightly weaker than H's Manchester subjects.

Table II.—Showing differences in the results of two operators with the Martin short test obtained from similar subjects in Manchester and Essex.

(The unbracketed figures in the columns headed "average strength" are the sums of the strengths in lbs. of the muscles tested. The figures enclosed in brackets are the standard deviations in lbs.)

Age	H's results.				E s results			
	Manchester.		Walthamstow (Essex).		Manchester.		Leyton (Essex).	
	No.of Subjects	Average Strength (and *s.d.*).	No of Subjects.	Average Strength (and *s.d.*)	No of Subjects.	Average Strength (and *s d.*).	No.of Subjects.	Average Strength (and *s.d.*).
14½—15 -	26	325 (55 09)	53	340 (68 69)	76	360 (69·57)	32	322 (77·47)
15 —15½-	20	342 (46 45)	35	371 (74 47)	74	387 (81·25)	38	349 (58·73)
15½—16 -	34	373 (63·56)	20	366 (51 53)	68	421 (93·48)	25	368 (60·79)
16 —16½-	28	389 (65·52)	19	424 (52·83)	73	442 (103·5)	29	379 (84·94)
16½—17 -	17	409 (60 36)	13	397 (51·32)	87	485 (111·0)	25	393 (93·55)
17 —17½-	19	440 (75 72)	8	480 (63 80)	74	527 (125·0)	12	405 (92·42)

These results are shewn graphically in Figure 1. They should be compared with the data given below for grip, height, and weight for Manchester and Essex subjects (*Tables IX, X,* and *XI*, and *Figures*, 3, 4, 5, and 6).

In partial explanation of these results, it may be stated that E obtained smaller results in Essex than in Manchester *after he had become acquainted with the fact that he was obtaining larger results than H* (*from subjects of identical type*).* It is natural to suppose this tendency to obtain smaller results to have been due to "suggestion." Of course, even if this supposition be

* A period of several months elapsed between E's operating at Manchester and at Leyton Technical Institute.

correct, it provides no explanation for the divergence between the results of the two operators.

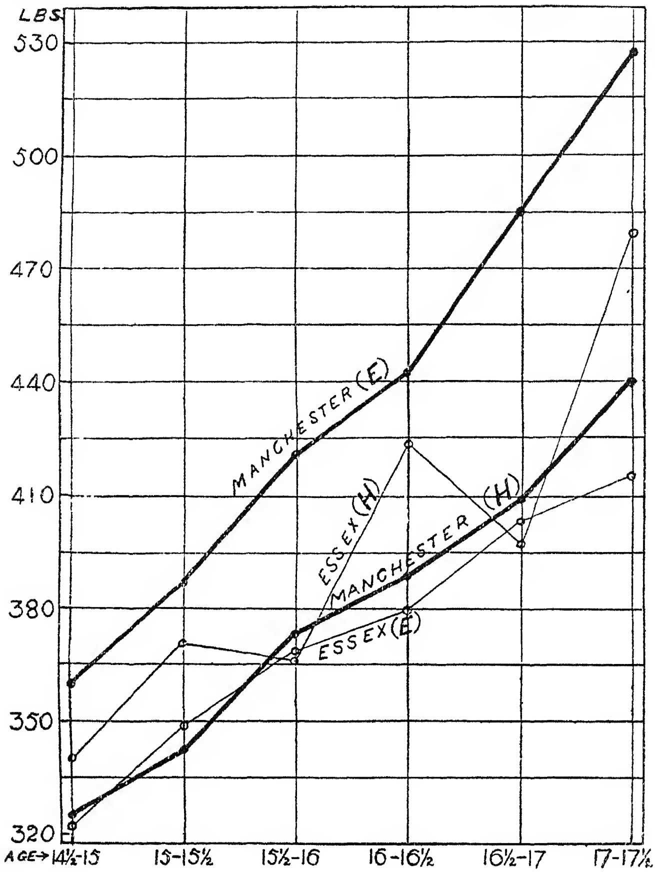

FIG. 1.—The influence of the operator on the Martin test. E and H are the two operators. Ordinates indicate strength in lbs. measured by the Martin short test.

The main conclusions are these. Results obtained by the Martin method are partly a function of the operator. Different operators may obtain different results when doing their utmost to adopt the same method, and the same operator may obtain different results at different times. It is therefore concluded that the Martin strength test is unsuitable for any general use in industry, and that it is valueless for the purpose of determining norms of strength, to obtain which was the primary aim of this investigation. Any norms given by it would be relative to the operator who obtained them, and any other results compared with them would be relative to the operator who obtained them : a comparison being made in such a case between two measures both unreliable.

The Martin short test has been suggested and to some extent used as a fatigue test. No direct evidence as to its utility in

this respect was obtained in the present investigation, but the indirect evidence was decidedly against it. Suggestion may at any time interfere with a performance test of fatigue.* If, however, as seems likely, the results obtained by the Martin test are influenced by suggestion on the part of the *operator* as well as on the part of the subject, the method would seem perfectly useless as a fatigue test.†

§ 7. The Reliability of the Martin short Test.

The question now arose whether, having regard to the main object of the investigation, any use could be made of the data obtained by the Martin method. It seemed possible that these

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* *Cf.* the following statement by Dr. R. A. Spaeth concerning the effects of suggestion on ergographic work: "If a man has been raising five or eight pounds for some time, he reaches a point where he can't work any longer; but if we remove a pound, the individual finds he can go on. We also find, that when certain individuals are told 'We are now removing a pound,' but actually add a pound instead of taking one off, the individual starts merrily on and proceeds to work. . . The thing I want to bring out is that the suggestion of work and the idea that one is capable of work plays a large part in actual performance. The reverse is quite true, as demonstrated by the fact that if I tell the individual that I have added a weight and really remove one, he says he cannot go any further. . . . We have repeatedly carried out this experiment by way of demonstrating that the working capacity is not a fixed base line."—*Industrial Education*, p. 204 (The Society of Industrial Engineers, 1920).

† There are, in my opinion, other objections to the Martin test in addition to that based upon the fact that results obtained by it are partly a function of the operator. Two may be mentioned :—

(1) The first concerns the principle of the test. *Resisting a pull* is not a *natural* method of exerting strength. It is doubtless true that more natural methods, such as that of the grip test, depend upon a subject's volition; but it is not true that volition is excluded when a *resistance* test is used. Martin's statement that if the command to resist is uttered sharply, an almost *reflex* maximum resistance is obtained from the subject, is far from being universally true. This is obvious in view of the variability of the results obtained by the Martin method. The difference between the smallest and largest of three successive pulls on one of the pectorals, for instance, may often be as much as 20 lbs. This is probably due to the awkwardness of the test from the point of view of the subject. The grip method, on the other hand, is perfectly natural, and yields much more uniform results. With regard to the element of volition, it is found that a subject generally desires to do his best in this test, especially when allowed to see the dial of the dynamometer during his grip. The test always proves popular.

(2) The second objection concerns the industrial value of the test. It was found in about 5 per cent. of the subjects that cramp resulted from the testing of the thigh abductors or adductors. Further, a subject would sometimes say the day after the test had been made on him that he was "stiff all over." (Such stiffness would probably be *lessened* by making only one pull on each muscle instead of three, and one pull would probably yield a reliable result for certain purposes—it would be definitely smaller than the biggest of three successive pulls. It is, however, very questionable if stiffness would in this way be altogether eliminated. *Cf.* above, p 9). Clearly, any test that acquires a reputation for being painful is not suitable for industry. The grip test is immune from any such danger.

data might be used for testing the value of the grip method as a means of measuring strength. For the *relative positions* assigned to members of a group by the Martin method might be much the same for one operator as for another, even though the various results for one operator were consistently higher than the corresponding results for the other. If so, the method would yield a reliable indication of the relative strengths of the members of a group, and any other method yielding a high correlation with it could be regarded as a useful means of establishing strength standards; provided this latter method were reliable, and gave results not affected by the experimenter. The first question to be answered therefore was : to what extent are the *positions* given to the various members of a group of subjects by the Martin method to be relied upon?

For the purpose of answering this question the test as described above was made four times on the same group of nineteen subjects, pupils at the (Cambridge) Melbourne Place Central School for Boys.* The subjects were about 15 years of age, the youngest being $14\frac{1}{2}$ years and the oldest $15\frac{1}{2}$ years. As the operating was carried out by E the results relate to the reliability of the Martin method in giving positions to the members of a group

TABLE III.—*The figures in the columns for the tests are the sums of the strengths in lbs. of the muscles tested by the Martin Short Method as described above.*

Subject.	Age.	Test I	Test II.	Test III.	Test IV.
A	$14\frac{4}{12}$ yrs	510	467	438	402
B	$14\frac{11}{12}$,,	353	432	426	405
C	$14\frac{6}{12}$,,	407	391	425	390
D	$15\frac{4}{12}$,,	413	382	358	365
E	$14\frac{7}{12}$,,	342	316	359	373
F	$15\frac{6}{12}$,,	345	354	339	349
G	$15\frac{3}{12}$,,	357	351	354	320
H	$15\frac{6}{12}$,,	308	336	340	335
I	$14\frac{2}{12}$,,	340	319	318	312
J	$14\frac{11}{12}$,,	309	285	317	324
K	$14\frac{9}{12}$,,	321	298	268	287
L	$15\frac{2}{12}$,,	290	284	299	299
M	$15\frac{1}{12}$,,	282	316	295	257
N	$14\frac{4}{12}$,,	310	302	276	253
O	$14\frac{6}{12}$,,	266	265	287	287
P	$14\frac{10}{12}$,,	272	287	237	224
Q	$14\frac{9}{12}$,,	232	259	251	263
R	$14\frac{1}{12}$,,	226	233	235	239
S	$14\frac{10}{12}$,,	201	197	194	200

* I wish to acknowledge my indebtedness to Mr. Martin, headmaster of this school, for his kindness in giving every facility for carrying out these tests.

when the operator is not changed. Comparative results might have been obtained from several *relatively untrained* operators; but differences shown in such results would have been of doubtful interpretation. In any case, the procedure adopted was adequate for the purpose.

The tests were made on Tuesday and Wednesday of one week, and on Monday and Tuesday of the next, on each occasion between 10 a.m. and noon. The results for all nineteen subjects in the four tests are given in *Table III*.

The arrangement of the group by the Martin method is nearly the same on all four occasions. The degree of correspondence* between the results of the four tests in shown in *Table IV*.

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* The correlation formula used throughout this report is the Pearson "product moment" formula adapted to rank differences, namely, $r = 1 - \frac{6S(d^2)}{n(n^2 - 1)}$, where d = rank difference, and n = the number of subjects ranked. As considerable use is made below of the correlation method, the calculation of a coefficient is given here to illustrate the actual procedure in obtaining correlation coefficients. The case taken is that of finding the coefficient between the first and second tests at the Melbourne Place School.

The calculation of the coefficient.

Subject.	Test I.		Test II.		Difference of Rank in Tests I. and II.	Rank Difference Squared (d^2)
	Strength in lbs.	Rank.	Strength in lbs.	Rank		
A	510	1	467	1	0	0
B	353	5	432	2	3	9
C	407	3	391	3	0	0
D	413	2	382	4	2	4
E	342	7	316	$9\frac{1}{2}$	$2\frac{1}{2}$	6·25
F	345	6	354	5	1	1
G	357	4	351	6	2	4
H	308	12	336	7	5	25
I	340	8	319	8	0	0
J	309	11	285	14	3	9
K	321	9	298	12	3	9
L	290	13	284	15	2	4
M	282	14	316	$9\frac{1}{2}$	$4\frac{1}{2}$	20·25
N	310	10	302	11	1	1
O	266	16	265	16	0	0
P	272	15	287	13	2	4
Q	232	17	259	17	0	0
R	226	18	233	18	0	0
S	201	19	197	19	0	0

$S(d^2) = 96{\cdot}50$

Now r (the correlation coefficient)

$$= 1 - \frac{6S(d^2)}{n(n^2 - 1)} = 1 - \frac{6 \times 96{\cdot}5}{19 \times 360} = 1 - {\cdot}08.$$

$= {\cdot}92.$

[*Continued in note on next page*

TABLE IV.—*Inter-correlation coefficients of four tests with the Martin Method, the operator being the same for all four tests.*

	Test I.	Test II.	Test III.	Test IV.
Test I. - -		·92	·88	·84
Test II. - -	·92		·89	·82
Test III. - -	·88	·89		·96
Test IV. - -	·84	82	·96	

The average coefficient of each test with all the others is + ·89, and the reliability coefficient of the test—the coefficient of the first and fourth tests combined, with the second and third tests combined—is very high, namely, + ·95. It has to be borne in mind that an *absolutely* reliable test could not be expected to give identical positions to the members of a group on two occasions, since normal changes in the relative fitness of some subjects would result in the real positions of the members of a group *not* being *absolutely* identical on any two occasions. In view of this fact and the high correlations obtained between the four tests,

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In view of recent controversies among statisticians concerning different methods of computing correlation coefficients, it may be of interest to state here that for several chance groups of the subjects dealt with in this report, "product moment" r's were calculated for comparison with the "rank method" r's for the same groups. The differences between the r's calculated by these two methods for the selected groups were statistically negligible; and since the distributions of the factors measured were much the same at all ages, it may be assumed that this relationship between the two sorts of r's would hold throughout the data. The r's calculated for the chance groups by the two methods are given in the following table :—

Manchester Data.	r by Rank Method	r by Product Moment Method.
"Total Strength" (*Martin Test*) and Weight. Age 15–15½ (*see Table VI*).	·69 ± ·04	·695 ± ·041
"Total Stength" and Grip. Age 15–15½ (*see Table V*).	·71 ± ·04	·720 ± ·038
"Total Strength" and Weight. Age 16½–17 (*see Table VI*).	·54 ± ·05	·592 ± ·047
"Total Strength" and Grip Age 16½–17 (*see Table V*).	·52 ± ·05	·532 ± ·052

we may accept as *very reliable* the *relative positions* given by the Martin test to a group of subjects tested by the one operator. And such relative positions should indicate differences in *general* strength.

The next question concerns the degree of correlation between the Martin test results and the data for height, weight, and strength of grip. It would be possible to use height, weight, and grip standards as strength standards provided that these correlated highly with the Martin test.

§ 8. Correlations of Height, Weight, and Grip with Strength measured by the Martin short Method.

Correlation coefficients were calculated for a large number of groups of subjects. Height, weight, and grip (the average of right and left hands) all correlated positively and significantly with the Martin test. Height yielded the lowest and most variable correlation, while that for grip was approximately equal to that for weight. When grip and weight were combined,* the resulting coefficients were rather higher than for either separately, but when height was combined with weight and grip the resulting ing coefficients were no higher than those for grip and weight alone, and were often slightly lower. Typical results are shown in *Tables V , VI., VII., and VIII.*

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* Combination was effected by summing ranks for grip and weight and making a new ranking by reference to the summed ranks. This new ranking was then correlated with the Martin test ranking. The procedure was similar when height was combined with grip and weight.

TABLE V. HAND GRIP. *Showing correlation coefficients of hand grip (average of right and left hands) with strength determined by the Martin Method, all subjects in any one group being those tested by one operator.*

Age.	Subjects from Essex Industries.			Subjects from Manchester.			Subjects from Leyton Technical Institute.		
	No. of Subjects.	*r.*	*p.e.**	No. of Subjects.	*r.*	*p.e.**	No. of Subjects.	*r.*	*p.e.**
13–13½ -	0	—	—	0	—	—	28	·63	·08
13½–14 -	0	—	—	15	·61	·11	37	·71	·06
14–14½ -	24	·37	12	53	·58	06	31	·75	·06
14½–15 -	52	·72	·05	76	·53	·06	32	·85	·03
15–15½ -	54	72	·04	74	·71	·04	38	·82	·04
15½–16 -	53	·78	·04	68	·66	·05	25	·78	·05
16–16½ -	54	·72	·04	73	·51	·06	29	·82	·04
16½–17 -	40	·76	·05	87	·52	·05	25	·78	·05
17–17½ -	57	·82	·03	74	·70	·04	12	·80	·07
17½–18 -	40	·62	·07	56	·40	·08	16	·78	·07
18–18½ -	42	·65	·06	29	·62	·08	9	Not calcu-lated.†	
18½–19 -	40	·49	·08	11	Not calcu-lated †	—	6	,,	
19–19½ -	35	·54	·08	4	,,	—	6	,,	
19½–20 -	40	·38	·10	5	,,	—	8	,,	
Average	44	·63	063	60	·58	·063	27	·77	·055

* It may be accepted that a coefficient of correlation is not due to chance when it is three (or more) times its probable error (*p.e.*). But of course there is no question of coefficients of the general size here shown being due to chance.

† Because of the small number of subjects.

TABLE VI.—WEIGHT. *Showing correlation coefficients of weight with strength determined by the Martin Method, all subjects in any one group being those tested by one operator.*

Age.	Subjects from Essex Industries.			Subjects from Manchester.			Subjects from Leyton Technical Institute.		
	No of Subjects.	*r.*	*p.e.*	No. of Subjects.	*r.*	*p.e.*	No. of Subjects.	*r.*	*p.e.*
13–13½ -	0	—	—	0	—	—	28	·50	·10
13½–14 -	0	—	—	15	·66	·10	37	·70	·06
14–14½ -	24	·29	·13	53	·66	·05	31	·67	·07
14½–15 -	52	·60	·06	76	·61	·05	32	·79	·05
15–15½ -	54	·58	·06	74	·69	·04	38	·84	·03
15½–16 -	53	·74	·04	68	·76	·05	25	·69	·07
16–16½ -	54	·67	·05	73	·63	·05	29	·80	·05
16½–17 -	40	·82	·04	87	·54	·05	25	·82	·05
17–17½ -	57	·68	·05	74	·65	·05	12	·62	·12
17½–18 -	40	·56	·08	56	·33	·08	16	·79	·07
18–18½ -	42	·65	·06	29	·48	·10	9	Not calcu-lated.*	
18½–19 -	40	·39	·09	11	Not calcu-lated.*	—	6	,,	
19–19½ -	35	·70	·06	4	,,	—	6	,,	
19½–20 -	40	·54	·08	5	,,	—	8	,,	
Average	44	·60	·067	60	·60	·062	27	·72	·067

TABLE VII.—STANDING HEIGHT. *Showing correlation coefficients of standing height with strength determined by the Martin Method, all subjects in any one group being those tested by one operator.*

Age.	Subjects from Essex Industries.			Subjects from Leyton Technical Institute.		
	No. of subjects.	*r.*	*p.e.*	No. of subjects	*r.*	*p.e.*
13–13½ - -	0	—	—	28	·39	·11
13½–14 - -	0	—	—	37	·64	·07
14–14½ - -	24	·31	·13	31	·65	·07
14½–15 - -	52	·54	·07	32	·63	·07
15–15½ - -	54	·42	·08	38	·73	·05
15½–16 - -	53	·58	·06	25	·60	·09
16–16½ - -	54	·48	·07	29	·48	·10
16½–17 - -	40	72	·05	25	·48	·11
17–17½ - -	57	·49	·07	12	·29	18
17½–18 - -	40	·25	·10	16	·62	·11
18–18½ - -	42	·47	·08	9	Not calculated.*	
18½–19 - -	40	·17	·11	6	,,	
19–19½ - -	35	·24	·11	6	,,	
19½–20 -	40	·08	·11	8	,,	
Averages -	44	39	·086	27	·55	·096

* Because of the small number of subjects

TABLE VIII.—*Showing coefficients for grip and weight combined, and for grip, weight and height combined, with total strength, as measured by the Martin short Test. Coefficients for grip alone and weight alone (with the Martin Test) are included for comparison. All subjects in any one group were tested by the one operator.*

Subjects from Essex Industries

Age.	No. of Subjects.	Grip (alone) *r.*	Weight (alone) *r.*	Grip and Weight combined. *r.*	Grip, Weight and Height combined *r.*
13 —13½ -	0	—	—	—	—
13½—14 -	0	—	—	—	—
14 —14½ -	24	·37	·29	·34	·34
14½—15 -	52	·72	·60	·72	·70
15 —15½ -	54	·72	·58	·91	·85
15½—16 -	53	·78	·74	·81	·81
16 —16½ -	54	·72	·67	·73	·64
16½—17 -	40	·76	·82	·84	·80
17 —17½ -	57	·82	·68	·77	·72
17½—18 -	40	·62	56	·69	·52
18 —18½ -	42	·65	·65	·71	·68
18½—19 -	40	·49	·39	·53	·38
19 —19½ -	35	·54	·70	·72	·62
19½—20 -	40	·38	·54	·59	·47
Averages -	44	·63	·60	·70	·63

Table VIII.—*cont.*

Subjects from Leyton Technical Institute.

Age	No. of Subjects	Grip (alone) r.	Weight (alone) r.	Grip and Weight combined. r.	Grip, Weight and Height combined. r.
13 —13½ -	28	·63	·50	·62	·58
13½—14 -	37	·71	·70	·75	·75
14 —14½ -	31	·75	·67	·75	·73
14½—15 -	32	·85	·79	·86	·83
15 —15½ -	38	·82	·84	·85	·83
15½—16 -	25	·78	·69	80	·73
16 —16½ -	29	·82	·80	86	80
16½—17 -	25	·78	·82	·85	·75
17 —17½ -	12	·80	·62	·80	·56
17½—18 -	16	·78	·79	·84	·76
18 —18½ -	9	Not* calculated	Not* calculated	Not* calculated	Not* calculated
18½—19 -	6	,,	,,	,,	,,
19 —19½ -	6	,,	,,	,,	,,
19½—20 -	8	,,	,,	,,	,,
Averages -	27	·77	·72	·80	·73

* Because of the small number of subjects.

In practically every case the correlation (with "total strength"—the Martin test) for grip and weight (combined) is higher than the corresponding correlation for either grip or weight alone; but the increase in the size of the coefficients due to such combination is never great, and consequently an estimate of "total strength" based on it would not be much more accurate than an estimate based on either factor alone. In making such an estimate, however, standing height may be entirely neglected.* With two exceptions (in 22 groups) the coefficients for height, weight, and grip (combined) with strength measured by the Martin method are lower than the corresponding coefficients for weight and grip (combined) simply.

* The relations between Martin Test and weight, grip, and height have also been worked out by obtaining the partial and multiple correlation co-efficients and the regression lines by the product moment method. These results confirm those given above, the precision of prediction being greater with grip and weight than with height.

Graphical representation of the correlation results for the subjects from the Essex industries is given in Figure 2.

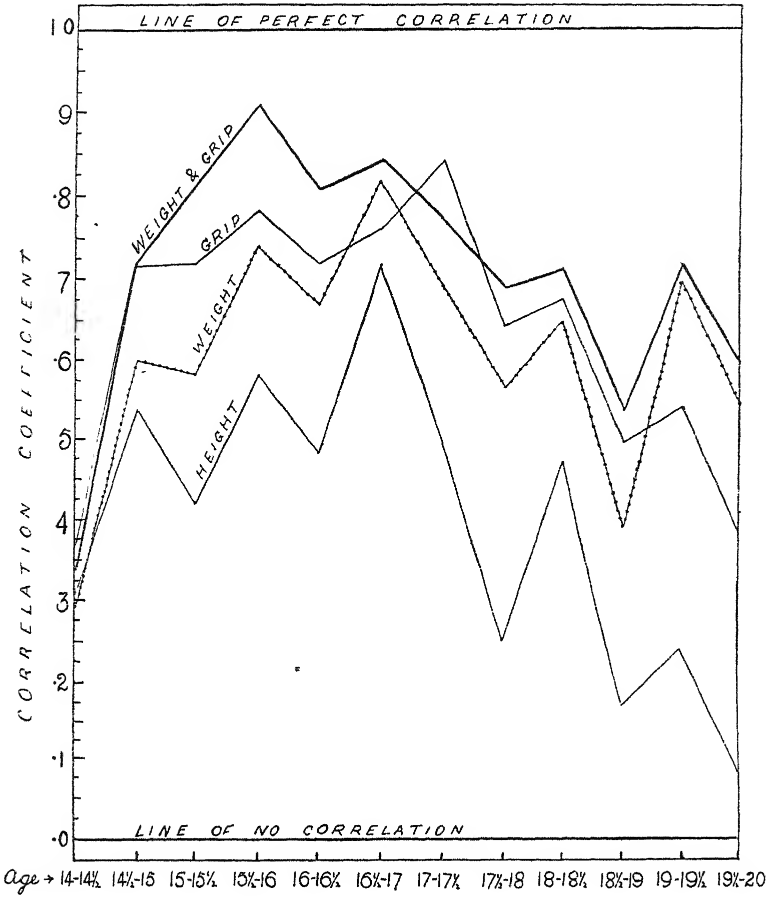

FIG. 2.—Data giving these curves represent subjects from Essex industries. The individual curves indicate the size of the correlation coefficients of "total strength" (Martin Test results) at different ages with standing height, weight, grip and weight and grip combined. (*See* first part of *Table VIII*, p. 55).

§ 9. CONCLUSIONS FROM THE FOREGOING RESULTS.

The main conclusion to be drawn from the foregoing correlation results is that a combination of weight and grip may be accepted as a useful measure of an individual's *general* strength.*

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* Martin and Rich emphasize the fact that in their group of 56 adult subjects the strength of the finger flexors (tested by the Martin method) correlated with total strength to a lower degree (·47 for the right flexors and ·50 for the left) than that of any other muscles, and state that "the original selection of the grip as a criterion of bodily strength was perhaps unfortunate" (*Am. J. Physiol.*, 1918, *47*, 32–33). This position is supported

[*Continued on next page*

though an estimate based upon either grip alone or weight alone would be nearly as good.* These conclusions apply to subjects of the ages tested.

There seems to be some indication that this measure of strength is especially reliable for youths between the ages of 15 and 17. Thus, while the average correlation for grip and weight (combined) with the Martin test for the twelve age groups from 14 to 20 in Essex industries is ·70, the average for the six age groups from 14½ to 17½ is ·80, and that for the four age groups from 15 to 17, ·82 (*cf. Fig.* 2). For the Leyton subjects all coefficients are higher† than for the subjects from the Essex industries. Here the average coefficient for weight and grip (combined) with the Martin test for all ages (from 13 to 18) is ·80; but for the six age groups from 14½–17½ this average is ·837, and for the four age groups from 15 to 17 it is ·84. There is at any rate no indication of the relative unrelia-

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by the general fact that (in the group of 56) muscles with short leverage, such as the finger flexors, correlated less highly with total strength than muscles with long leverage. At the same time, it is necessary to be cautious in arguing from coefficients obtained with a single group of subjects, as may be seen from the results given above. For instance, the coefficient for grip with the Martin test for a group of 57 subjects aged 17–17½ in the present investigation was ·82, while that for 40 subjects aged 17½–18 was ·62 (*vide* Table VIII.). Possibly, Martin and Rich would have obtained higher coefficients for the finger flexors with other groups. At any rate, the results given above show *average* correlations of grip with the Martin test (total strength) ranging from ·58 to ·77—these being average correlations from 10 groups of subjects; *i.e.*, the *lowest average* in this investigation is higher than the coefficients from which Martin and Rich argue. It is only fair to add that Martin and Rich used the resistance method for testing finger flexor strength, and that they suggest that their coefficients are probably lower "than would be given by tests taken with perfected instruments of the Smedley type" (*ibid.*, p. 33).

* It is not contended that this method of estimating strength is perfect. If other tests as convenient and reliable as the Smedley dynamometer grip test were devised, the use of these *plus* grip *plus* weight should yield a still better estimate of general strength than that given by grip and weight (combined) alone.

Possibly one such test should aim at testing the forearm flexors, *though not by the resistance method.* In the present investigation it was found that these were the most satisfactory muscles included in the short test, from the point of view of the technique of the test. No cramp was ever experienced by a subject as a result of having them tested, and the variation in the three pulls for each subject was smaller for these than for any other of the six muscle groups. Further, Martin and Rich found (*Am. J. Physiol.*, 1918, *47*, 32), that these muscles correlated especially well with total strength—the correlation coefficients for a group of 56 adult subjects were ·89 for the right forearm flexor and ·91 for the left. As these coefficients are higher than that obtained in the present investigation with the grip test—higher even than the correlations of grip and weight (combined)—it would seem well worth while to construct a test for these muscles (involving a *positive pull* so that the result would not be influenced by an operator) to be used along with grip and weight in the estimation of general strength.

† Due, possibly, to a more parallel development in the various units of the total musculature. Specialised industrial work might be expected to produce inequalities in development.

bility of the suggested measure of strength between the ages of $14\frac{1}{2}$ and $17\frac{1}{2}$. Hence, during the period in which a youth's vocation is likely to be finally decided upon, vocational guidance may operate, so far as strength is involved, with some assurance.

There remains, however, the problem of determining to what extent adolescent strength correlates with adult strength; that is, to what extent a youth who is, say, stronger than 70 per cent. of the youths of his age will later be stronger than 70 per cent. of the adults of his age. It would therefore be valuable to measure the strengths of some one fairly large group of adolescents at half-yearly intervals over a number of years. If this were done in some large concern in which employment is practically permanent, and if the attempt were made to correlate changes in relative strength with the nature of an individual's occupation and habits, an important contribution would certainly be made to the present subject.

For vocational guidance purposes, the data obtained in the present investigation for weight and grip (the average for the two hands) are arranged in percentile tables, to which reference has already been made (*vide* § 5 and Appendix I.). These tables should prove useful even though data obtained from much larger numbers of subjects would probably yield tables differing from them slightly in many parts.

One important feature of the data needs emphasis. This is the considerable *range** shown by the subjects for both grip and weight. The average range per age group for all ages examined in Essex, is, for weight 81 lbs., and for grip 32 kgms.; and the corresponding averages for Manchester, for the eight age groups for which sufficient data were obtained to yield significant conclusions, are 74 lbs. and 31·5 kgms. The range for each age group is given in the percentile tables. The smallest grip observed in each age group is approximately 40 per cent. of the largest.†

This is clearly of importance in connection with occupations, such as various sorts of assembling, in which strength of hand rather than general bodily strength is required. It may be noted that Link found strength of grip to correlate positively with efficiency in asembling.‡

§ 10. Comparison of the Manchester and Essex Subjects.

In the Anthropometric Committee's final report§ in 1883 to the British Association for the Advancement of Science, it was shown that the inhabitants of various parts of the British Isles exhibited characteristic differences as regards physical features

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* The difference between the largest and the smallest records.

† In Essex the *average* percentage for *all* age groups is 40, and in Manchester, for the eight age groups given in the percentile tables, it is 38.

‡ H. C. Link, *Employment Psychology*, Chs. IV and VI. Macmillan, 1919.

§ This report dealt with standing height, weight, and other physical characteristics of the inhabitants of the British Isles.

when compared with the inhabitants of other parts. In view of the main object of the present investigation, the question thus arose to what extent strength measures derived from subjects in one part of the country are applicable to subjects in another. To obtain an answer to this question, it was essential that the subjects examined in any two parts of the country should be of the same social and industrial class, as the Anthropometric Committee's report showed that there are important physical differences between different social and industrial classes in any one part of the country. Now the Manchester subjects in the present investigation were as similar in these respects to the Essex subjects (especially to those examined at the Leyton and Walthamstow Technical Institutes) as any two groups are ever likely to be. It may, therefore, be accepted that the differences found to obtain between these Manchester and Essex subjects represent typical differences between the inhabitants of these two parts of the country. As will be seen from the data given below, these differences are definite and considerable as regards the characteristics measured. This is shown in Tables IX., X., and XI., which give averages for eight age groups—those between 14 and 18. Results for other age groups are omitted on account of the fewness of subjects in such age groups, either in Manchester or Essex.

TABLE IX.—HAND GRIP. *The unbracketed figures for grip are the averages for the right and left hands* (i.e., *the averages of the biggest of three grips with the right hand and the biggest of three grips with the left*) *in kilograms. The figures enclosed in brackets are the standard deviations in kilograms.*

Age.	Walthamstow and Leyton (*combined*).		Manchester.	
	No. of Subjects.	Grip (Av. of R. and L. hands and s.d.).	No. of Subjects.	Grip (Av. of R. and L. hands and s.d.).
14 —$14\frac{1}{2}$ - -	68	29·12 (6·26)	56	25·95 (5·53)
$14\frac{1}{2}$—15 - -	85	32·08 (6·73)	102	27·59 (5·57)
15 —$15\frac{1}{2}$ - -	73	34·76 (6·68)	94	28·99 (5·97)
$15\frac{1}{2}$—16 - -	45	35·18 (7·19)	102	32·26 (6·55)
16 —$16\frac{1}{2}$ - -	48	38·39 (6·22)	101	32·93 (7·42)
$16\frac{1}{2}$—17 - -	38	38·35 (5·81)	104	35·55 (6·71)
17 —$17\frac{1}{2}$ - -	20	41·43 (6·03)	93	36·87 (7·53)
$17\frac{1}{2}$—18 - -	26	45·30 (7·20)	77	39·85 (6·38)

The average difference for the eight age groups between the Essex and Manchester subjects for strength of grip as given by

the data in *Table IX.* is 4·33 kilograms. Graphical representation of this result is given in *Figure* 3 on page 62.

TABLE X.—WEIGHT. *Weight is given to the nearest lb. (Unbracketed figures are the averages, and figures enclosed in brackets the standard deviations.)*

Age	Leyton.		Walthamstow.		Manchester.	
	No. of Subjects.	Average Weight in lbs. (and s.d.).	No. of Subjects	Average Weight in lbs (and s.d.).	No. of Subjects.	Average Weight in lbs. and (s.d.).
14 —14½	31	94 (15·4)	37	93 (17·3)	56	86 (14·8)
14½—15	32	101 (16·7)	53	99 (14·8)	102	91 (15·4)
15 – 15½	38	109 (16·1)	35	107 (16·7)	94	93 (13 9)
15½—16	25	112 (13·3)	20	105 (18·3)	102	101 (15·5)
16 —16½	29	117 (13·4)	19	110 (15·5)	101	104 (16 8)
16½—17	25	117 (13·5)	13	112 (15·5)	104	108 (14·2)
17 —17½	12	120 (16·4)	8	129 (13·0)	93	112 (16·9)
17½—18	16	128 (15·2)	10	130 (9·5)	77	118 (13·6)

The Leyton subjects show a weight roughly identical with that of the Walthamstow subjects. There is, however, a considerable difference between the Leyton and Walthamstow results, on the one hand, and the Manchester results, on the other. The average difference for the eight age groups between the Manchester and Walthamstow subjects is 9 lbs., and that between the Manchester and Leyton subjects 10·6 lbs. Graphical representation of these results is given in *Figure* 4 on page 63.

TABLE XI.—STANDING HEIGHT. *The figures given for standing height are inches. (Standing height was not measured at Walthamstow.) (The unbracketed figures are averages, and the figures enclosed in brackets standard deviations.)*

Age.	Leyton.		Manchester.	
	No. of Subjects.	Average Standing Height in ins. (and s.d.).	No. of Subjects.	Average Standing Height in ins. (and s.d.).
14 —14½ - -	31	60·81 (3·72)	56	58 64 (3·34)
14½—15 - -	32	62·21 (3·64)	102	59·73 (3·36)
15 —15½ - -	38	63·18 (3·09)	94	60·22 (3·23)
15½—16 - -	25	64·80 (3 81)	102	61·93 (3·70)
16 —16½ - -	29	65·35 (2·86)	101	62·81 (3·43)
16½—17 - -	25	65·59 (2·34)	104	63·27 (2·82)
17 —17½ - -	12	65·38 (2·82)	93	63·87 (2·96)
17½—18 - -	16	66·59 (2·17)	77	64·80 (2·85)

The difference between the Manchester and Leyton subjects as regards standing height is very marked. The average difference per age group calculated from the data of *Table XI.* is 2·33 inches. Graphical representation of the results of *Table XI.* is given in Fig. 5 on page 64.

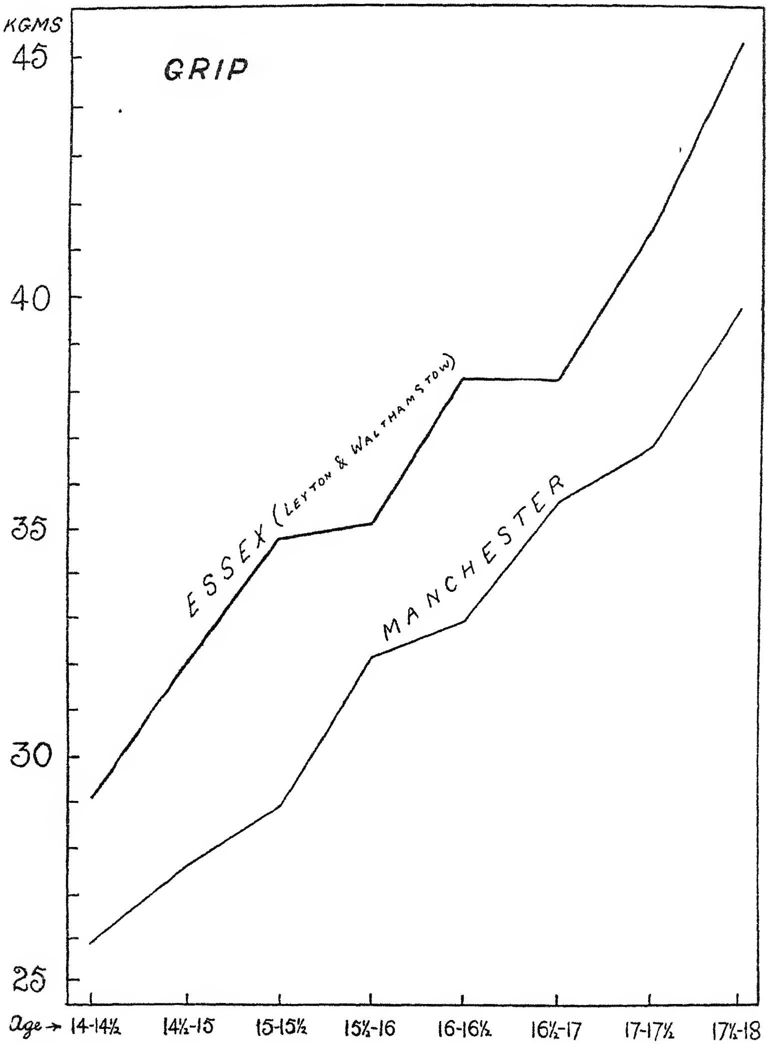

FIG. 3.—Hand grip of different age groups—Manchester and Essex.

The differences between the Manchester and Essex subjects have been indicated through a comparison of the *averages* for grip, weight, and standing height of the various age groups. The consistency of the results suggests the inference that these differences would be distributed in a fairly uniform manner over the whole of the subjects in corresponding age groups. That this is so is shown in Fig. 6, which gives percentile curves for grip

for three age groups in Manchester and Essex. These curves have been drawn from the percentile tables presented in

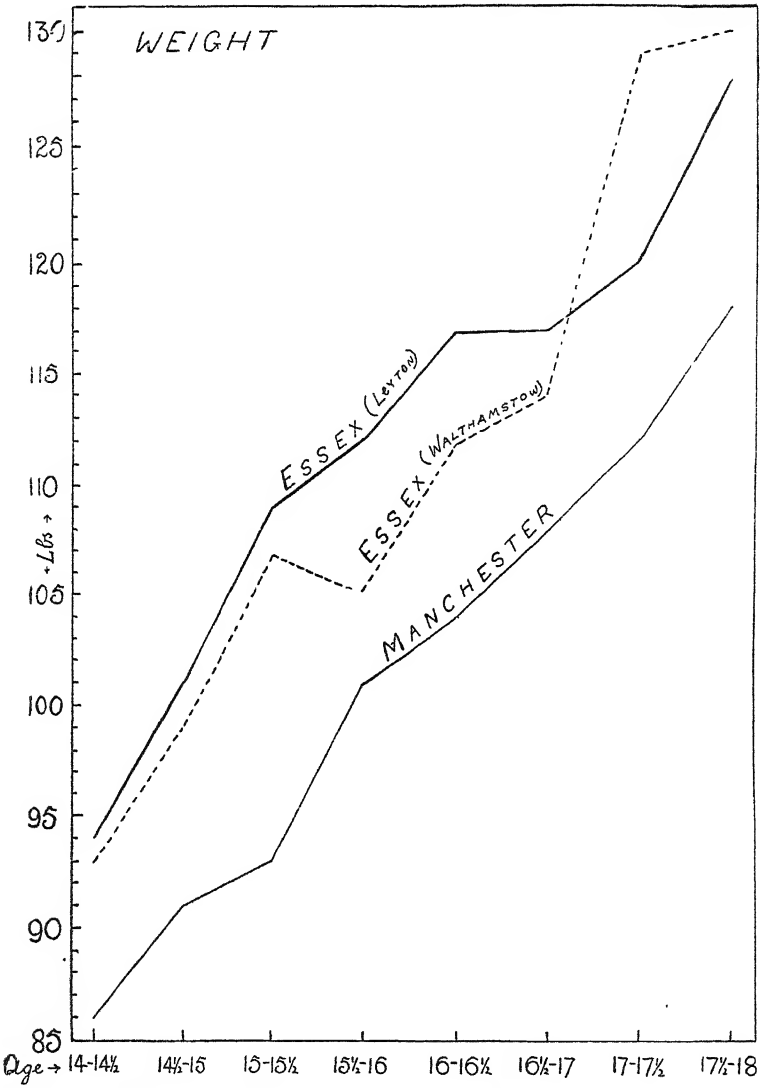

FIG. 4.—Weight of different age groups—Manchester and Essex.

Appendix I. Curves for three age groups only are shown, as a larger number would have obscured the relationship between the Essex and Manchester results on account of the overlapping of the curves for certain age groups at Manchester with those for lower age groups at Essex; but the results for *any* age group are similar to those shown in Fig. 6, as may be seen from a comparison of the relevant percentile tables. Exactly similar curves might also be drawn for weight, as may be seen from a comparison of the percentile results for this factor (Appendix I.).

The only point to observe with regard to Fig. 6 is that the curves for Essex shown in it represent results obtained from *all* the Essex subjects, and not merely from the Walthamstow and Leyton subjects. This, however, introduces no significant difference of any kind. On the whole, it *possibly* tends to diminish the differences already shown to exist between Essex and Manchester, as the subjects from Essex industries seem to have given results just noticeably lower than the Leyton and Walthamstow subjects. At any rate, they certainly did not give *higher* results than those. The differences between Essex

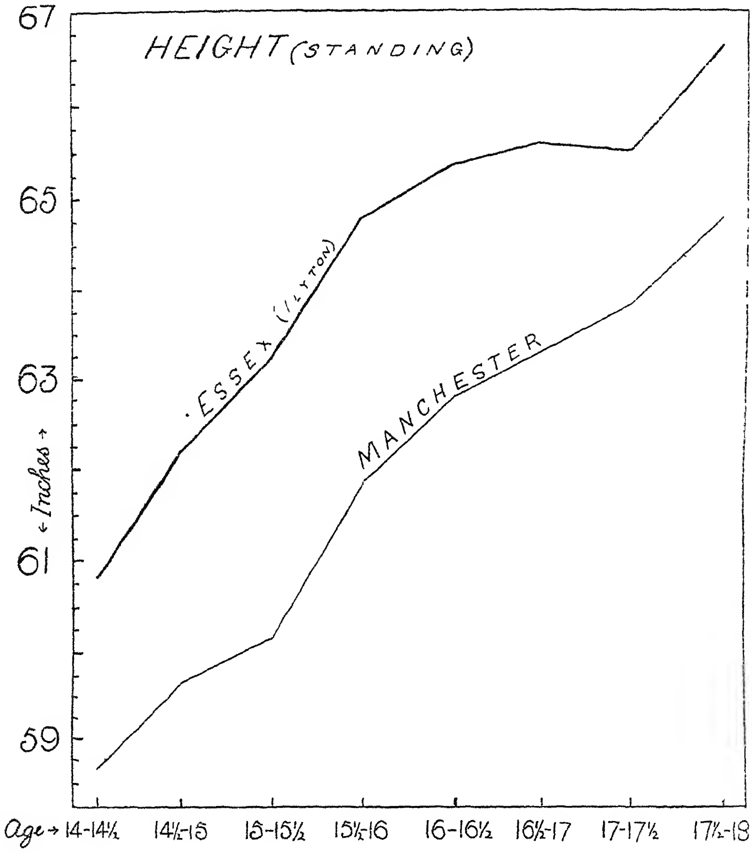

FIG. 5.—Standing height of different age groups—Manchester and Essex.

and Manchester shown in Fig. 6 (page 65) are, therefore (if anything), rather smaller than would be given by subjects of absolutely identical industrial class in the two localities.

Summarising the main tendency of the preceding data, we may say that Essex adolescent males are definitely superior physically to Manchester adolescent males; and that between the ages of 14 and 18 the Essex youth is approximately $2\frac{1}{3}$ inches the taller, 10 lbs. the heavier, and the stronger in hand grip by

$4\frac{1}{3}$ kilograms.* This statement applies to subjects of the class examined.

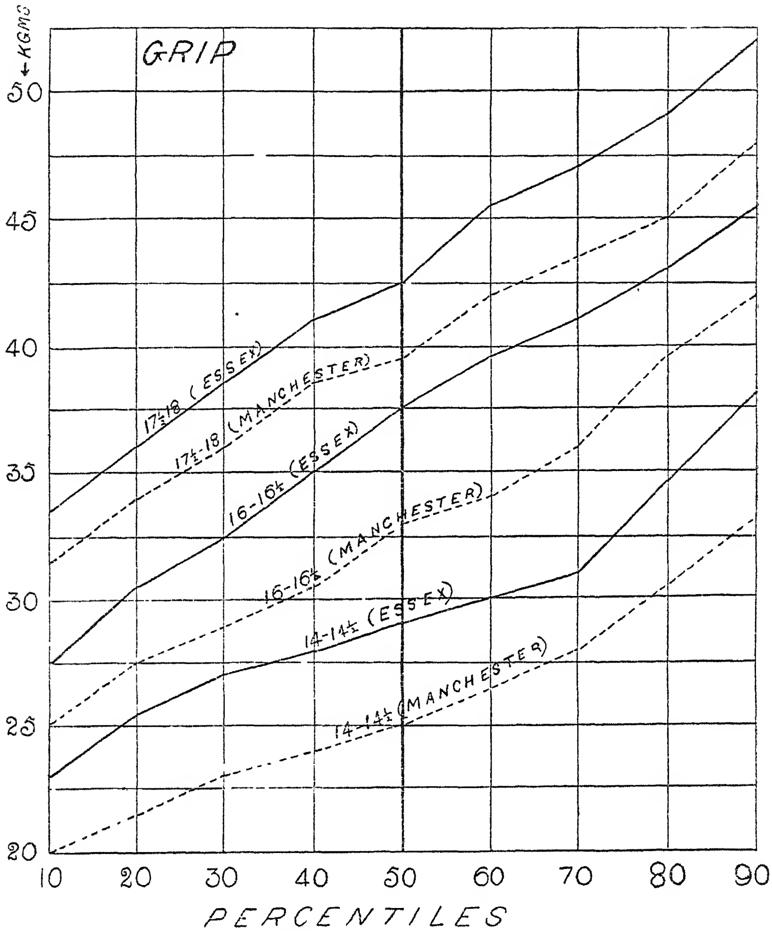

Fig. 6.—Showing that the difference in strength of grip between the Essex and Manchester subjects is distributed over the whole of the subjects in the various age groups.

In view of these results, it is concluded that norms of strength should be determined for different parts of the country, and that any set of measures derived from a given locality cannot be used (for comparing any individual with others of his age and district) in any other locality until investigation shows that it is applicable there. Tables indicating norms (averages and deviations) based

* It would be highly interesting to determine what *mental* differences, if any, there are between Essex and Manchester youths.

It is natural to suppose that the physical differences found to exist between Essex and Manchester are connected with differences in "race." There is, however, no reliable knowledge concerning such "race" differences, though it is to be expected that Essex contains a much larger proportion of persons of Anglo-Saxon origin than Lancashire.

upon the data collected in this investigation are, therefore, given for Essex and Manchester separately (Appendix I.).

Such differences in physique, and especially in strength, as those here shown to exist between Essex and Manchester adolescent males, are possibly of considerable industrial significance. If, on relatively heavy work, the efficiency of a Manchester man is as high as that of an Essex man, it may be expected, assuming identical working methods, that the Manchester man expends greater effort in his work than the Essex man, and in consequence suffers greater fatigue. It is clear, at any rate, that the poorer the physique the greater the need for vocational guidance on the basis of strength, from the point of view of both fatigue and efficiency; as in such conditions there is more chance of a man being engaged on work for which he is not sufficiently strong than where physique is relatively superior.

It should be noted that, while a combination of grip and weight gives a useful indication of general strength, it is not known to what extent it measures *endurance*, and it is possible that in this quality the Manchester subjects were equal to the Essex subjects, though there is no evidence that this was so. The basis of endurance would seem to offer an important subject for investigation in connection with the general problem of industrial fatigue. It may be recalled that one of the men who, in Taylor's pig-iron case, shifted $47\frac{1}{2}$ tons of metal per day for several years, was a small man whose weight was about 130 lbs.*

§ 11. Summary and Conclusions.

1. The Martin strength test is unsatisfactory for general industrial use, chiefly because results obtained by it are partly a function of the particular operator.

2. A combination of strength of grip and weight gives a useful indication of general strength. A better indication would almost certainly be obtained by the addition of the strength of the forearm flexors. On the other hand, estimates based on grip alone or on weight alone are nearly as good as estimates based on the two combined.

3. Essex adolescent males engaged in engineering are physically superior to Manchester adolescent males engaged in the same type of work. The average difference amounts to, approximately, $2\frac{1}{3}$ inches in standing height, 10 lbs. in weight, and $4\frac{1}{3}$ kilograms in strength of grip.

4. Percentile tables for grip and weight representing data obtained from over 1,400 Essex adolescent males and over 700 Manchester adolescent males are given in Appendix I. While not absolutely reliable owing to the relatively small numbers of subjects from whom they were derived, these tables should prove useful for vocational guidance with reference to such occupations as make heavy demands on physical strength.

* F. W. Taylor, *Shop Management* (1911 edn., p. 50).

5. It is possible that a certain number of those who at present become engineering apprentices do not possess the physique required for engineering work, and it seems probable that these could continue in engineering on very light types of work only, if regard is had to fatigue and efficiency. It is possible that this applies to all those whose average percentile for grip and weight is below 10*—that is, to the weakest 10 per cent.

It must be emphasised that this suggestion is based upon impressions only, as the present investigation did not attempt to deal with the problem of determining minimum standards of strength for *any* occupation (*cf.* § 1).

If this suggestion be correct, some decrease in fatigue and inefficiency could be effected by guiding the weakest 10 per cent. of these youths into vocations where physical strength is not required, and in substituting for them others of more adequate physique—a relatively easy task in view of the widespread desire to engage in engineering occupations. This, of course, is only a small part of what might be done by a general adaptation of worker to occupation on the basis of strength.

Appendix I.

Percentile Tables for Weight and Grip (the Average for the Right and Left Hand, taken with the Smedley Dynamometer) obtained from Manchester and Essex Youths engaged, or about to be engaged, in Industry, chiefly Engineering.

(1) *Definition of a Percentile.*—Any percentile, p, is a value of the feature measured (in this case grip or weight), such that there are p per cent. of the observed values below it and $100 - p$ per cent. above it: a value equal to the 10 percentile, for instance, having 10 per cent. of the observed values below it and 90 per cent. above it.

(2) *Use of the Percentile Tables.*—Suppose it is desired to compare the grip and weight of a certain Manchester youth (of similar industrial class to the subjects of this investigation) between 14 and 14½ years of age, with the values shown in the Manchester tables, and suppose, *grip having been measured by the method described in* § 4 (*b*), this youth shows an average grip of 24 kgms. and a weight of 86 lbs. Then proceed as follows:—

(*a*) First, obtain by reference to the tables the percentiles corresponding to the observed grip and weight. It will be seen that the percentile corresponding to the observed grip of 24 kgms. is 40, and the percentile corresponding to the observed weight of 86 lbs. is 60. These percentiles mean (approximately) that, as regards grip, this youth is stronger than 40 per cent. of the youths of his age and class and weaker than 60 per cent., while as regards weight he is stronger than 60 per cent. of the youths of his age and class, and weaker than 40 per cent. (Tables XII. and XIII.)

If the estimate of *general strength* is being based upon either grip alone *or* weight alone, it may be assumed for comparative purposes that the percentile for either factor corresponds to the percentile for general strength (though this will not be strictly true, as the correlation of either factor with general strength is not perfect). Further, in the hypothetical case given in the preceding

* At least, in the younger age groups.

paragraph, the estimate of general strength would be somewhat different according as it was based upon one factor or the other. If *grip* were the basis of the estimate, we should say that (as regards general strength) the given youth was probably stronger than 40 per cent. of the youths of his age and class and weaker than 60 per cent.; while if the estimate were based on weight we should say that he was probably stronger than 60 per cent. of the youths of his age and class and weaker than 40 per cent.

(*b*) Second, to obtain from grip and weight *combined* an estimate of *general strength*, proceed by averaging the percentiles found for grip and weight. As the supposed percentile for grip is 40 and that for weight 60, the average percentile is 50. This may be taken to mean that it is probable that this particular youth has 50 per cent. of the youths of his age and class above him in *general strength* and 50 per cent. below him—*i e.*, that he is near the average in general strength of his age and class (and district).

The further the average thus obtained from the two percentiles for grip and weight is above (or below) 50, the further is the youth likely to be above (or below) the average of his age and class in general strength.

(*c*) It will sometimes happen than an observed value for grip or weight is not identical with any value given in the percentile tables. In such cases, other percentiles may readily be interpolated between those (the deciles) given. For instance, suppose the Manchester youth above had shown an average grip of 24·5 kgms. instead of 24 kgms. As the 40 percentile for his age is 24 kgms., and the 50 percentile 25 kgms., 24·5 kgms. may be taken as the value of the percentile midway between 40 and 50 (the 45th percentile) as 24·5 is midway between 24 and 25. A similar procedure may be adopted generally.

(3) *Reliability of the Tables.*—The tables are not absolutely reliable in all parts on account of the relatively small number of subjects from whom they are derived. The values enclosed in brackets are conjectural, and represent approximations to the values that would be obtained by smoothing away certain of the more noticeable irregularities in the percentile curves. They are probably more reliable than the values obtained directly from the data, though in all cases these are given at the foot of the tables. The extent of the "corrections" thus made is indicated, in the figures corresponding to the tables, by dotted lines.

It is recommended that anyone using these tables should keep exact records of the values for grip and weight shown by all those whose grip and weight are compared with the values given in the tables. They will thus be able, by means of the values observed by themselves, gradually to correct any tendency in the tables to exaggerate or diminish the grip or weight of specific groups. The tables given here represent a starting point only.

(4) *Range.*—The figures in the columns headed "range" (in lbs. or kgms.) represent the differences between the smallest and largest observed value in the various age groups.

(5) In the tables given below (for both Manchester and Essex) the number of subjects for grip at either place is not identical with that for weight at the same place. This discrepancy is due to various incidental factors which made it impossible to go through the whole routine of the testing with *every* subject.

TABLE XII.—WEIGHT (MANCHESTER).

Age.	No. of Sub-jects.	Range in lbs.	Percentiles.								
			10	20	30	40	50	60	70	80	90
14 —14½	56	58	69	70	75	80	83	86	95	98	109
14½—15	102	77	70	77	83	85	90	93	97	105	111
15 —15½	94	65	76	82	(86)*	89	91	97	102	(108)†	112
15½—16	102	67	79	87	93	97	101	105	111	115	123
16 —16½	101	89	81	89	96	100	104	109	112	117	125
16½—17	104	70	90	97	101	105	109	113	116	118	126
17 —17½	91	110	91	98	104	111	112	116	119	124	135
17½—18	77	57	100	104	110	112	116	121	125	132	137

* Value obtained from data directly = 83.
† „ „ „ „ =104.

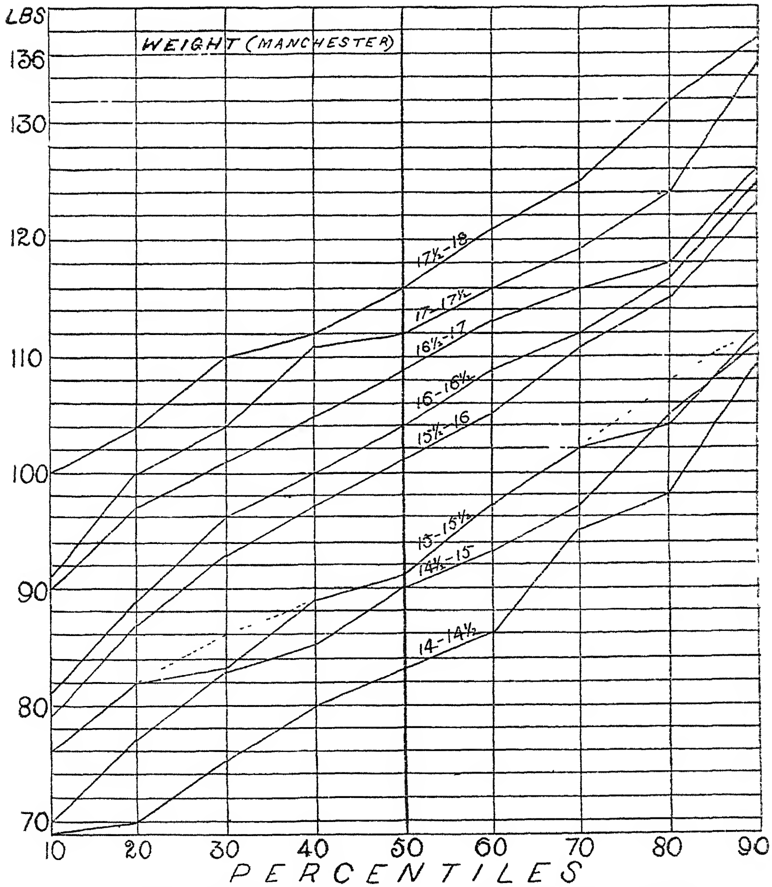

FIG. 7.—Graphical representation of results in TABLE XII.

Table XIII.—Grip (Manchester).

Age.	No. of Subjects	Range in Kgms	Percentiles.								
			10	20	30	40	50	60	70	80	90
14 —14½	56	27·5	20	21·5	23	24	25	26·5	28	30·5	33
14½—15	101	30·0	21·5	23·5	24·5	25·5	27	28·5	29·5	31	36
15 —15½	93	26·0	22	24	26	27	29	31	32	33·5	(38)†
15½—16	102	31·5	24	26·5	28·5	30	31·5	33·5	35·5	38·5	40·5
16 —16½	100	40·5	25	27·5	29	30·5	(32·5)*	34	36	39·5	42
16½—17	98	35·0	26·5	30·5	31·5	33·5	35	36·5	39·5	41·5	44
17 —17½	83	33·5	27·5	31	32·5	34	37·5	40	41·5	43·5	46·5
17½—18	71	28·5	31·5	34	36	38·5	39·5	42	43·5	45	48

* Value obtained from data directly = 31·5.
† ,, ,, ,, = 35·5.

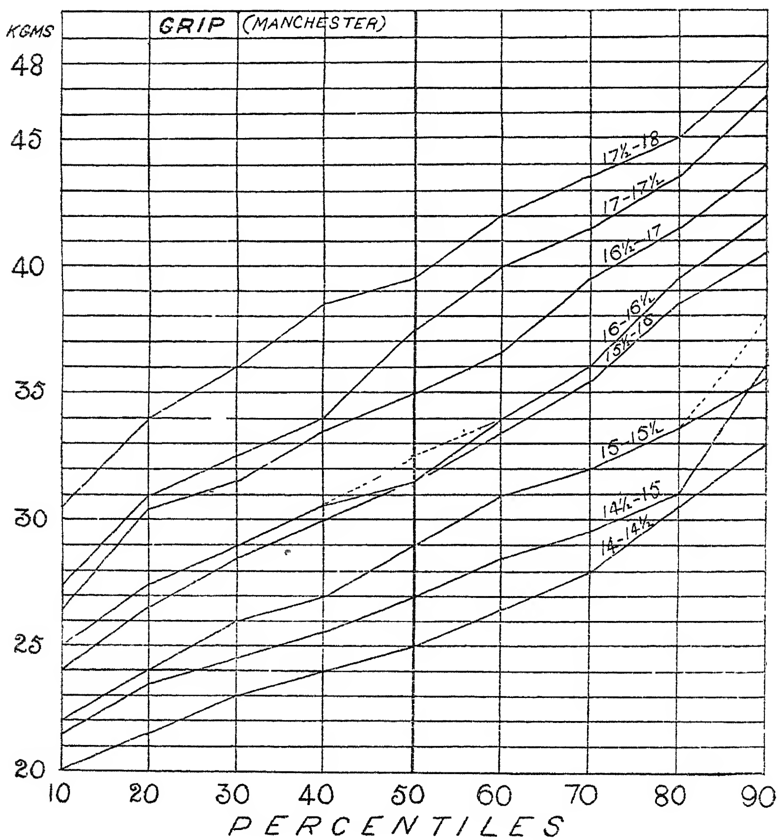

Fig 8.—Graphical representation of results in Table XIII.

TABLE XIV.—WEIGHT (ESSEX).

Age	No of Subjects	Range in lbs	PERCENTILES. 10	20	30	40	50	60	70	80	90
13 —13½ -	59	69	68	73	75	79	80	82	85	89	93
13½—14 -	104	67	72	77	80	84	87	89	93	95	106
14 —14½ -	113	91	74	81	86	90	92	95	101	108	118
14½—15 -	180	102	81	86	89	93	97	101	107	113	122
15 —15½ -	159	85	85	90	95	99	104	108	112	116	124
15½—16 -	122	76	(88)[1]	(94)[2]	(98)[4]	102	109	112	116	123	129
16 —16½ -	120	81	91	99	104	110	114	117	120	124	134
16½—17 -	110	78	98	103	109	113	117	119	124	129	138
17 —17½ -	116	86	102	108	113	117	120	126	130	(133)[10]	142
17½—18 -	105	78	106	(111)[3]	117	120	124	(129)[6]	132	136	143
18 —18½ -	102	87	108	114	119	124	129	132	135	139	144
18½—19 -	70	70	111	119	123	125	130	134	(137)[8]	141	145
19 —19½ -	68	72	114	121	126	129	133	136	(138)[9]	142	(149)[11]
19½—20 -	65	91	116	124	126	129	(133)[5]	(136)[7]	139	142	151

1 Value obtained from data directly = 84.
2 „ „ „ „ = 90.
3 „ „ „ „ = 114.
4 „ „ „ „ = 95.
5 „ „ „ „ = 132.
6 „ „ „ „ = 126.
7 „ „ „ „ = 135.
8 „ „ „ „ = 139.
9 „ „ „ „ = 137.
10 „ „ „ „ = 136
11 „ „ „ „ = 152.

[For Figure 9 *see* page 72].

TABLE XV.—GRIP.—ESSEX.

Age.	No of Subjects	Range in Kgms.	PERCENTILES. 10	20	30	40	50	60	70	80	90
13 —13½	58	25·5	19·5	22	23·5	24·5	25·5	26	27	28	30·5
13½—14	103	24·0	21·5	22·5	(25)[6]	(26)[9]	26·5	27·5	29	30·5	33
14 —14½	112	33·0	23	25·5	27	28	29	30	31	34·5	38
14½—15	180	33·5	25	26·5	28	30	31·5	33	34·5	36·5	41
15 —15½	161	36·0	26·5	28·5	30	31	32·5	34	36	38·5	41·5
15½—16	122	38·0	(27)[1]	(29·5)[4]	30·5	32·5	34	36	37·5	41·5	43·5
16 —16½	117	42·0	27·5	30·5	32·5	35	37·5	39	41	43	45·5
16½—17	105	27·5	30·5	(32)[5]	35	37·5	39	41	43·5	46	48
17 —17½	107	39·5	(32)[2]	34	(37)[7]	40	41·5	43·5	45·5	48	51
17½—18	99	37·0	33·5	36	38·5	41	42·5	45·5	47	49	52
18 —18½	101	31·0	35·5	37	40	42	43·5	46	47·5	50·5	53·5
18½—19	69	32·0	(37)[3]	39	41	43·5	45·5	46·5	48·5	(52)[12]	(55)[14]
19 —19½	62	26·5	39	42	44	45·5	46·5	48·5	50·5	53	56·5
19½—20	64	26·5	40	42	(44)[8]	(46)[10]	47	48·5	(51)[11]	(53)[13]	(56·5)[15]

1 Value obtained directly from data = 25
2 „ „ „ „ = 30
3 „ „ „ „ = 34·5
4 „ „ „ „ = 28·5
5 „ „ „ „ = 34
6 „ „ „ „ = 23·5
7 „ „ „ „ = 38·5
8 „ „ „ „ = 43·5
9 „ „ „ „ = 24·5
10 „ „ „ „ = 45
11 „ „ „ „ = 49
12 „ „ „ „ = 49·5
13 „ „ „ „ = 51·5
14 „ „ „ „ = 52·5
15 „ „ „ „ = 51

[For Figure 10 *see* page 73.]

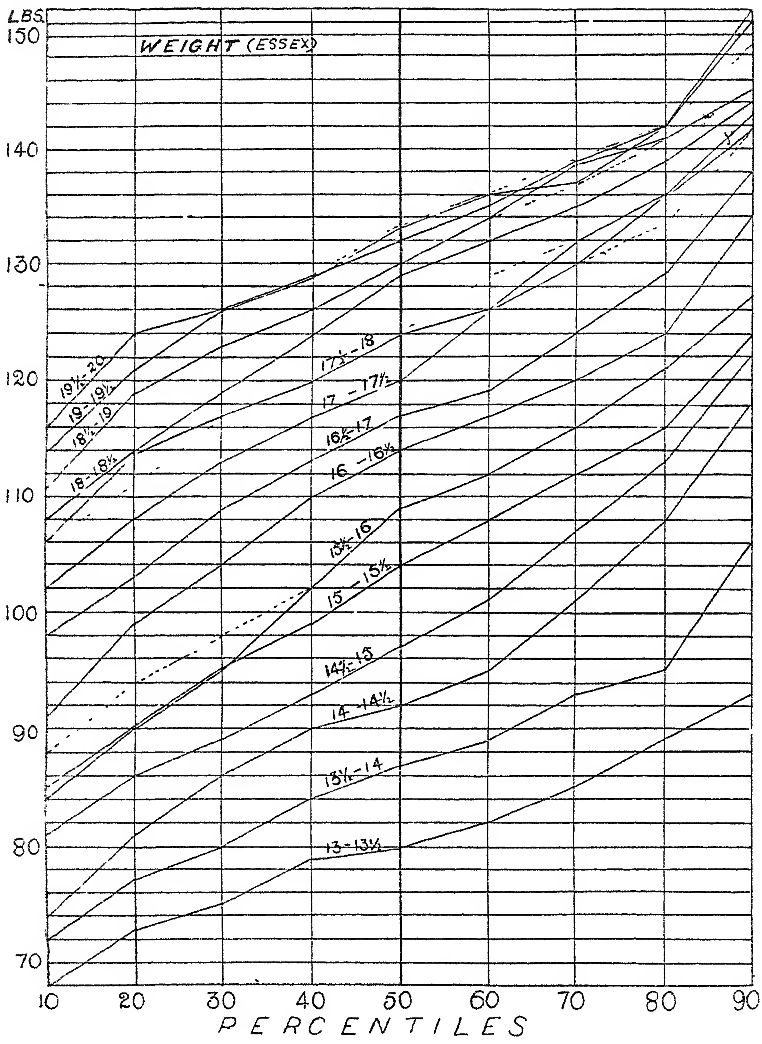

FIG. 9.—Graphical representation of results in TABLE XIV.

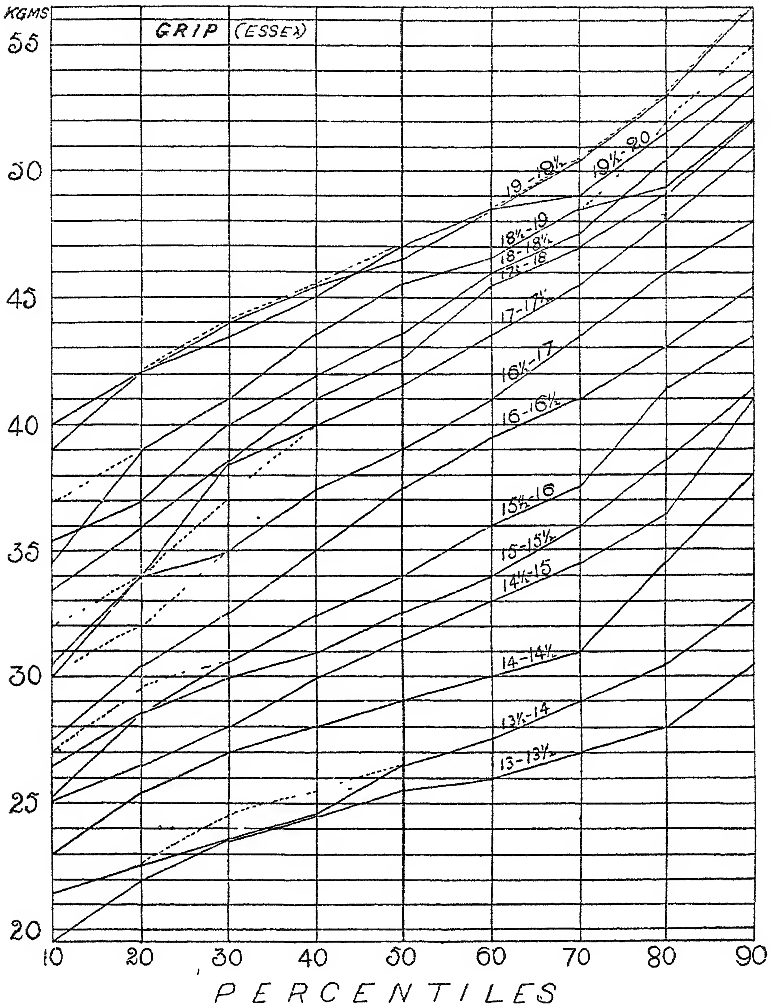

FIG. 10.—Graphical representation of results in TABLE XV.

APPENDIX II.

As frequency distribution data are fundamental in statistical work, Tables (XVI—XIX) are added giving these data for grip and weight both in Manchester and Essex (pp. 74-77).

TABLE XVI.

Frequency-distribution of Weights of Manchester adolescent males, between the ages of 14 and 18, engaged in engineering.

Age.	Weight in lbs.																				No. of subjects.
	58 to 62	63 to 67	68 to 72	73 to 77	78 to 82	83 to 87	88 to 92	93 to 97	98 to 102	103 to 107	108 to 112	113 to 117	118 to 122	123 to 127	128 to 132	133 to 137	138 to 142	143 to 147	148 to 152	153 to 157	
14–14½	—	4	7	9	8	6	4	5	7	3	—	—	3	—	—	—	—	—	—	—	56
14½–15	2	3	6	11	8	16	15	13	5	8	8	2	1	1	1	2	—	—	—	—	102
15–15½	—	2	2	11	7	12	15	12	6	12	7	2	5	—	1	—	—	—	—	—	94
15½–16	1	1	3	3	7	5	10	15	11	9	14	7	6	9	1	—	—	—	—	—	102
16–16½	—	1	1	2	6	7	10	6	14	13	17	5	7	6	—	3	—	1	—	2	101
16½–17	—	—	—	3	3	2	7	6	14	13	15	15	11	6	5	2	1	1	—	—	104
17–17½	—	—	—	2	—	3	3	6	8	9	16	11	15	5	4	3	4	2	—	—	91
17½–18	—	—	—	—	—	—	2	1	7	10	14	6	8	10	6	6	5	2	—	—	77
Totals	3	11	19	41	39	51	66	64	72	77	91	48	56	37	18	16	10	6	0	2	727

TABLE XVII.

Frequency-distribution of strengths of grip of Manchester adolescent males, between the ages of 14 and 18, engaged in engineering.

Age.	Strength of Grip (average of Right and Left Hands) in Kgms.																							No. of subjects
	15 to 16·5	17 to 18·5	19 to 20·5	21 to 22·5	23 to 24·5	25 to 26·5	27 to 28·5	29 to 30·5	31 to 32·5	33 to 34 5	35 to 36 5	37 to 38 5	39 to 40·5	41 to 42·5	43 to 14·5	45 to 46·5	47 to 48·5	49 to 50·5	51 to 52·5	53 to 54·5	55 to 56·5	57 to 58·5	59 to 60 5	
14–14½	1	2	3	8	13	9	6	4	5	1	2	1	—	—	1	—	—	—	—	—	—	—	—	56
14½–15	2	1	5	6	18	17	18	12	6	3	8	4	—	1	—	—	—	—	—	—	—	—	—	101
15–15½	—	—	2	12	8	12	13	9	14	13	6	3	—	1	—	—	—	—	—	—	—	—	—	93
15½–16	—	1	—	5	6	9	10	16	13	8	9	7	9	3	2	3	1	—	—	—	—	—	—	102
16–16½	—	—	2	3	4	7	10	21	9	11	7	7	8	4	4	1	—	—	1	—	—	—	1	100
16½–17	—	—	—	2	—	9	7	5	15	11	14	8	8	10	7	—	—	—	1	—	1	—	—	98
17–17½	—	1	—	1	1	3	6	6	12	10	4	9	11	8	7	—	1	3	—	—	—	—	—	83
17½–18	—	—	—	—	—	1	—	5	7	5	9	4	11	9	9	5	2	2	2	—	—	—	—	71
Totals	3	5	12	37	50	67	70	78	81	62	59	43	47	36	30	9	4	5	4	0	1	0	1	704

TABLE XVIII.

Frequency-distribution of Weights of adolescent males between the ages of 13 and 20 in industrial Essex.

Age.	Weight in lbs.																								No. of subjects.
	58 to 62	63 to 67	68 to 72	73 to 77	78 to 82	83 to 87	88 to 92	93 to 97	98 to 102	103 to 107	108 to 112	113 to 117	118 to 122	123 to 127	128 to 132	133 to 137	138 to 142	143 to 147	148 to 152	153 to 157	158 to 162	163 to 167	168 to 172	173 to 177	
13–13½	—	4	7	9	17	10	4	4	1	2	—	—	—	—	1	—	—	—	—	—	—	—	—	—	59
13½–14	2	1	7	13	14	15	20	13	8	2	5	3	—	1	—	—	—	—	—	—	—	—	—	—	104
14–14½	—	4	3	8	11	12	21	14	9	7	6	7	5	4	—	1	—	—	—	1	—	—	—	—	113
14½–15	—	1	4	7	10	20	26	26	17	20	10	17	7	7	3	1	2	1	—	—	—	—	1	—	180
15–15½	—	—	1	2	7	16	12	16	19	21	19	17	8	8	3	3	4	1	1	1	—	—	—	—	159
15½–16	—	2	1	5	2	8	13	9	9	9	17	18	5	12	7	4	1	—	—	—	—	—	—	—	122
16–16½	—	—	1	—	1	4	8	5	14	8	15	20	18	6	8	7	3	—	2	—	—	—	—	—	120
16½–17	—	—	—	—	—	1	3	5	9	8	14	18	13	15	8	5	3	2	4	1	—	1	—	—	110
17–17½	—	—	—	—	—	1	4	2	6	7	12	14	16	13	13	10	7	6	2	—	1	1	1	—	116
17½–18	—	—	—	—	—	—	3	1	2	6	6	13	19	15	10	11	9	5	1	1	2	—	1	—	105
18–18½	—	—	—	—	—	—	1	—	2	6	7	10	10	11	16	15	10	5	3	3	1	—	1	1	102
18½–19	—	—	—	—	—	—	1	—	—	3	4	3	9	13	6	9	10	6	4	—	2	—	—	—	70
19–19½	—	—	—	—	—	—	—	—	—	2	4	3	8	5	11	16	6	5	2	2	2	1	—	1	68
19½–20	—	—	—	—	—	—	—	—	—	—	2	4	4	10	13	9	10	4	3	1	3	1	—	—	65
Totals	2	12	24	44	62	87	116	95	96	101	121	147	122	120	99	91	65	35	22	10	11	4	4	2	1,493

TABLE XIX.

Frequency-distribution of strengths of Grip of adolescent males between the ages of 13 and 20 in industrial Essex.

Age.	Strength of Grip (Average of Right and Left Hands) in Kgms.																									No. of Subjects
	15 to 16·5	17 to 18·5	19 to 20·5	21 to 22·5	23 to 24·5	25 to 26·5	27 to 28·5	29 to 30·5	31 to 32·5	33 to 34·5	35 to 36·5	37 to 38·5	39 to 40·5	41 to 42·5	43 to 44·5	45 to 46·5	47 to 48·5	49 to 50·5	51 to 52·5	53 to 54·5	55 to 56·5	57 to 58·5	59 to 60·5	61 to 62·5	63 to 64·5	
13–13½	—	3	5	6	11	14	8	6	2	1	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	58
13½–14	2	1	6	14	19	13	14	14	8	7	2	1	2	—	—	—	—	—	—	—	—	—	—	—	—	103
14–14½	1	2	2	4	10	13	23	15	17	6	1	8	4	1	—	2	2	1	—	—	—	—	—	—	—	112
14½–15	1	—	2	5	9	19	26	19	21	26	17	10	6	9	3	3	2	2	—	—	—	—	—	—	—	180
15–15½	—	—	2	5	3	7	17	21	30	22	13	11	12	6	3	3	1	2	1	1	1	—	—	—	—	161
15½–16	—	—	1	6	4	4	10	12	15	18	10	10	5	11	9	1	2	—	3	—	1	—	—	—	—	122
16–16½	—	—	1	1	1	8	5	7	13	7	14	10	14	13	11	3	5	2	1	—	—	—	—	1	—	117
16½–17	—	—	—	—	—	—	5	6	7	10	11	12	10	9	8	11	10	1	2	2	1	—	—	—	—	105
17–17½	—	—	—	—	2	—	3	6	4	7	5	7	14	13	7	12	10	7	4	1	—	3	—	1	1	107
17½–18	—	—	—	—	—	1	—	2	2	9	8	8	9	11	7	12	10	8	6	3	2	—	—	—	1	99
18–18½	—	—	—	—	—	—	1	1	4	3	7	9	7	12	13	11	7	7	6	6	3	4	—	—	—	101
18½–19	—	—	—	—	1	—	—	—	—	6	3	3	5	6	7	12	8	8	4	4	2	—	—	—	—	69
19–19½	—	—	—	—	—	—	—	—	—	—	2	1	5	7	8	9	8	6	3	6	3	1	2	1	—	62
19½–20	—	—	—	—	—	—	—	—	1	—	—	3	4	9	7	7	9	8	6	6	2	2	—	—	—	64
Totals	4	6	19	41	60	79	112	109	124	122	94	93	97	107	84	86	74	52	30	29	15	10	2	3	2	1,460

C.—PHYSICAL MEASUREMENTS IN A SWEET FACTORY

by

ERIC FARMER, M.A.

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§1.—INTRODUCTION.

During the experiments in motion study* it became clear that no very satisfactory work could be done in this direction. until some attempt had been made to determine how far natural peculiarities of mind and body were related to proficiency in work. The adoption of new methods of work suggested by the investigator was always followed by satisfactory results: but the same difference between the earning capacities of different workers existed, and in practically the same ratio, as when working on the old method. In order to go more closely into the problem of determining the various factors which make for proficiency, certain physical measurements were carried out as a preliminary to psychological tests which might be applied later.

§2.—METHODS ADOPTED.

Certain groups of hand workers using no machinery and paid on a piece-rate system were selected as subjects for the investigation. One group was composed of chocolate packers, another of girls putting slabs of chocolate into paper wrappings and sealing them with wax, and a third group was employed in dipping.†

The measurements taken were :—

(1) *End span*—from tip of little finger to tip of thumb.

(2) *Middle span*—from tip of middle finger to tip of thumb.

(3) *Fore span*—from tip of fore-finger to tip of thumb.

(4) *Length of middle finger.*

(5) *Width of middle finger.*

(6) *Length of little finger.*

(7) *Width of hand across the knuckles.*

(8) *Thickness of hand.*

(9) *Length of hand.*—In order to take this measurement the hand was bent to form, as far as possible, a right angle with the forearm. The measurement was taken from the outside bend of the wrist to the tip of the middle finger.

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* Motion Study in Metal Polishing, *Industrial Fatigue Research Board*, *Rep.* **15**.

† *See* Time and Motion Study, *Ibid. Rep.* **14**, Pt. II.

(10) *Thickness of wrist.*
(11) *Width of wrist.*
(12) *Length of arm*—from arm pit to tip of middle finger.
(13) *Length of forearm*—from the outside bend of the elbow to tip of middle finger.
(14) *Height standing.*
(15) *Height sitting.*
(16) *Grip*—left hand, right hand and both hands together.

In all cases both the right hand and left hand measurements were taken.

More measurements were taken than were afterwards found to be necessary, but this was done deliberately, since it was impossible to say which measurements would yield results. Certain parts of the body were measured more than once, but this could not be avoided, and moreover, it was thought possible that results might be obtained by comparing the ratios in which certain parts of a limb stood to the whole limb.

The first method adopted in dealing with these measurements was to divide the workers according to age, *i.e.*, those of 14, 15, 16. 17 and 18 years and over. The learners were also separated according to age. In each age a division was then made between those whose output was good and those whose output was bad, making the average the dividing line between the two groups. The high output group is henceforth referred to as the A group and the low output group as the B group.

The average of each measurement of the A and B groups was then taken to see if there was any marked difference between them.

§3.—Results Obtained.

Two distinct types were found—the long spanned and the short spanned. The detailed results can be seen in the following tables :—

Table I.

102 *Packers Average of A group and average of B group compared with average of A and B taken together. The plus sign is used when the average of the group is higher than the average of A and B; and the minus sign when it is lower than the average of A and B taken together.*

Measurement.	A	B
Length of spans	+	—
Length of middle fingers	+	—
Length of hand	+	—
Thickness of wrist	—	+
Width of wrist	+	—
Length of arm	+	—
Length of forearm	+	—
Height standing	+	—
Height sitting	+	—

TABLE II.

11 *Workers in Packet Department (similarly compared).*

Measurement.	A	B
Length of spans	—	+
Length of middle finger	—	+
Length of little finger	—	+
Height standing	—	+
Height sitting	—	+

TABLE III.

14 *Dippers (similarly compared).*

Measurement.	A	B
Length of spans	—	+
Length of little finger	—	+
Thickness of hand	+	—
Length of hand	—	+
Length of arm	- -	+
Height standing	-	+
Height sitting	-	+
Grip	+	—

It will be seen that the long-spanned type manifests itself in the "A" group among the packers and in the "B" group among the workers in the packet department and the dippers. The type was found to be more marked among the workers of 18 and over than among the younger workers. All the workers measured in the packet and dipping departments were over 18 years of age.

A difference of type having been established which seemed to bear some relation to proficiency, the measurements of another group of workers were taken in order to check those already taken.

Twenty-five packers all over 18 years of age in another chocolate factory were measured, and the data treated in the same way. The results were the same as those found among the packers in the first factory, *i.e.*, the long-spanned type manifested itself in the "A" group and the short-spanned in the "B" group. Unfortunately no group of workers could be found whose employment and method of pay would have been comparable with that of the packet and dipping departments.

The general characteristics of the two groups having been discovered, the method of correlation was adopted in order to determine more precisely the relation between these physical differences and proficiency in work. The span rank of each worker was determined by the average length of the six span measurements (*i.e.*, fore span, middle span, and end span of each hand). A further ranking was obtained by adding the standing

height to the average length of the arms of each worker. This ranking is henceforth known as reach. The other characteristics (*see* Table I) of the " A " group among the packers were assumed to correlate highly with these two features, since they are nearly all included within them.

The following table gives the various correlations that were worked out for each group :—

TABLE IV.

Packers over 18 Years of Age—Correlations.

Measurements.	Factory P (49 Workers).		Factory C (25 Workers).	
	Correlation.	Prob. Error.	Correlation.	Prob. Error.
Span—output - - -	+·15	±·09	+·34	±·12
Length of reach—output -	+·15	±·09	+·25	±·13
Length of reach—span -	+·43	±·08	+·65	±·07
Age—output - - -	+·38	±·08	—·29	±·12
Age—experience - - -	+·67	±·05	+·39	±·11
Age—span - - - -	+·37	±·08	+·03	±·13
Age—length of reach - -	+·03	±·09	—·18	±·13
Span—experience - - -	+·29	±·09	—·17	±·13
Experience—output - -	+·32	±·08	—·19	±·13
Partial Correlations.				
Span and output · Reach -	+·10	±·09	+·35	± 11
Output and reach · span -	+·10	±·09	+·05	±·13
Output and experience · span	+·29	±·09	—·14	±·13
Output and span · experience	+·062	±·10	+·32	±·12

The first thing to be noticed about these correlations is their agreement in some respects and their marked disagreement in others If we take the correlations with output in their order of magnitude, we find them to be :—

Factory P.		Factory C.	
Age - - -	+·38 ± ·08	Span - - -	+·34 ± ·12
Experience - -	+·32 ± ·08	Reach - -	+·25 ± ·13
Span - - -	+·15 ± ·09	Experience -	+·19 ± ·13
Reach - - -	+·15 ± ·09	Age - - -	—·29 ± ·12

Partial Correlations. (Factory P).

Output, Experience—Span - -	+·29 ± ·09
Span, Output—Reach - - -	+·10 ± ·09
Output, Reach—Span - - -	+·10 ± ·09
Output, Span—Experience - -	+·062 ± ·10

Partial Correlations (Factory C).

Span, Output—Reach - - -	+·35 ± ·11
Output, Span—Experience - -	+·32 ± ·12
Output, Reach—Span - - -	+·05 ± ·13
Output, Experience—Span - -	+·14 ± ·13

Of these partial correlation co-efficients the only ones to which significance can be attached are those between output and experience (keeping span constant) in Factory P, and span and output (keeping alternately reach and experience constant) in Factory C. As the samples are small the ordinary form of the probable error of a correlation co-efficient is of doubtful value; these three results have therefore been tested with the help of the tables for the distribution of the correlation co-efficient in small samples published in *Biometrika* XI., pp. 379 *et seq.* and in each case it is found that the correlation is significantly positive. No weight can be attached to any of the other partial correlation co-efficients as they are within the limits of random sampling. The difference between the results in the two factories may, therefore, be only due to the small size of the samples, or it might be partly explained by a comparison of the ages and length of experience of the two groups as given in the following table :—

Factory P.

Age. Years.	Per Cent.	
34	2·04	4·08%
26	2·04	
25	2·04	95·90%
23	6·12	
22	8·16	
21	18·37	
20	14·29	
19	26·52	
18	20·40	
	99·98	

Factory C.

Age. Years.	Per Cent.	
40 -	4	28%
39	4	
36	4	
35	4	
31	4	
27	4	
26	4	
23	16	72%
22	8	
21	4	
20	16	
19	20	
18	8	
	100	

Experience—

Years.	Per Cent.	
14	2	
10	2	
8	8	
7	8	
6	12	64%
5	28	
4	24	
3	6	
2	4	
1	2	
	96	

Experience—

Years.	Per Cent.
25	4
20	4
12	4
6	12
5	4
2	12
1	60
	100

We may perhaps assume that after the age of 25 increase of age is not likely to be accompanied by increased agility. In Factory C 28 per cent of the packers are over 25; in Factory P only 4 per cent. We may further assume that apart from age, increased experience would be accompanied by increased proficiency, but we cannot expect that such improvement with experience will continue steadily *ad infinitum.* In a simple occupation like chocolate packing, we are safe in assuming that with workers of over 18 years of age increased output will cease to accompany increased experience after several years. In Factory P 64 per cent. of the packers have had between 4 and 6 years' experience: in Factory C 60 per cent. of the packers have had only one year's experience.

It will be seen, therefore, that there is a small but significant correlation between span and output in C, but P gives an indeterminate result. This may be due to chance owing to the small number of observations, but it might be that there are other and more powerful factors operating in the latter case which have practically ceased to operate in the former. Experience must play a considerable part in P, but very little in C, because the workers have had either too much or too little experience for it to manifest itself in the correlation coefficients.

The correlation coefficient between span and output of 53 packers in Factory P (there was none under 18 in Factory C) was $-\cdot0062 \pm \cdot09$. This is again of no significance in itself, but the following table suggests that there is a very direct relation between age and output, but none whatever between age and span.

TABLE V.—*Age compared with (i) Output* and (ii) Span.*

No. of Workers.	Age.	Average Output.	Probability of a deviation of this size, or greater, arising by chance.	Average Span.	Probability of a deviation of this size, or greater, arising by chance.
6	17	30 7	·017	17·6 cm.	·948
14	16	24·7	·042	17·5 ,,	·819
10	15	21·5	·855	17·2 ,,	·542
23	14	16·5	less than ·0001	17·6 ,,	·705

It can be seen that there is a very direct relation between age and output but none whatever between age and span. All these workers are growing girls and their output depends primarily

* As the samples are small, the usual form of the probable error has not been used, but the probability calculated from the Tables given in *Biometrika*, XI., pages 414 *et seq.* for distribution of the mean of a small sample.

upon age, experience, and strength, and not upon length of span. The latter may in fact be detrimental to them at this period because it may indicate that they have outgrown their strength.

There is little to be said of the remaining correlations. Length of reach and span in both cases correlate fairly highly, as was to be expected. They were treated separately because the former can be altered by rearrangement of bench whereas the latter cannot. The correlation between age and experience is in both cases significant though larger in Factory P than in Factory C. The difference of age and experience in the two groups is sufficient to explain the higher coefficient in the case of P.

The correlation coefficients between age and span and experience and span are significant in P though not in C. It would appear therefore that length of span has a tendency to increase with practice, though such increase must be within definite limits. The younger ages and the more effective experience of the P group makes this increase obvious while the opposite conditions existing in the C group conceal it.

The correlation coefficients between age and length of reach are in neither case significant, which corresponds with the fact that actual growth in stature does not often occur after the age of 18 or 19.

Packet and Dipping Departments.

As in these two departments the short-spanned type manifested itself in the A group, the correlation coefficient was obtained for each department between shortness of span and high output. The results were :—

Packet Department. (11 workers, all over 18 years of age.) $+\cdot 62 \pm \cdot 12$.*

Dipping Department. (14 workers, all over 18 years of age.) $+\cdot 09 \pm \cdot 18$.*

The low correlation for the second groups is partly explained by the inclusion in it of one worker, well-known to the Investigator, whose output was exceptionally high. She was most industrious and never stopped working for a moment; in fact, amongst her fellow workers she was known as a " sweater " *i.e.* a person who works far too hard. If this worker is omitted from the group, the correlation coefficient becomes $+\cdot 31 \pm \cdot 18$.

The numbers in these two groups were too small to warrant any careful analysis of the data, but the difference of type manifested by the A groups as compared with the A groups of packers is sufficient to suggest that length of span is connected with the type of work and not with any *general* characteristics making for high output.

An attempt was made to arrive at some conclusions by comparing the ratio of certain measurements to others of which they formed part but was abandoned after a considerable amount of work, no results having been obtained. Disproportionate

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* Both these correlation coefficients have been tested as described on page 82, and both show a significantly positive correlation.

measurements were also examined and at one time it was decided to include this factor among those having a relation to proficiency, but the scheme was finally abandoned because the results from Factory C did not correspond with those from Factory P and also because it is almost impossible to guard against errors arising from human judgment.

§ 4.—Conclusions.

The results of these experiments seem to justify the conclusion that physical type plays a part—though a small one—in proficiency in work, and that it is related to the work in question and not to any *general* characteristic making for efficiency. It is obvious from the correlations that there are other and more powerful factors connected with proficiency which cannot be arrived at by physical measurement.

With the packers it was noticed that those whose output rank was low often obtained very high span ranking, whereas those whose span ranking was low very rarely obtained the highest output rank. If this is anything more than a coincidence, it would suggest that there are psychological factors at work, which prevent a worker whose physical qualities are well adapted to the work from doing really well at it, but that if a worker is physically ill-adapted, the psychological qualities which may help her rarely entirely overcome the physical handicap. The present data do not permit us to do more than notice the possibility of such a distinction between physical and psychological factors.

Before any satisfactory results can be obtained from physical measurements, we must endeavour to ascertain how far such differences as seem to play a part in efficient workmanship are developed by the occupation itself and how far they are innate qualities. In packing, for instance, the fingers are constantly used in an extended position, such as would tend to develop the length of the spans: in the packet and dipping departments the exact opposite is the case.

Moreover, there is a certain amount of selection constantly at work in factories. Packers are generally chosen on account of their nice hands, and such workers as apply and have not "nice hands" are put on to other work such as is done in the packet and dipping departments. The various measurements of the packers were compared with the average measurements of unselected groups of workers of the same age, but no difference between the two showed itself. The selection therefore that takes place when entering the factory seems to bear no relation to actual physical differences among workers.

Besides this method of selection there is always an unconscious selection going on within the factory. A worker who does not do well in one department often changes for another and this change sometimes occurs several times before the department is found where the process is best fitted to the worker's qualifications. It would be most instructive to examine workers who change from one department to another, in order to see if any

marked physical type showed itself among those rejected by each department.

Even if the physical qualities which appear to be related to proficiency are the result of practice, we still have to determine why some workers develop them, and others with the same amount of experience do not.

During the early period of a young worker's factory life, physical qualities such as have been dealt with in this report seem to play little part. It is also probable that any psychological aptitudes would play an almost equally small part. More general factors, such as good health, enthusiasm, desire to earn money, good home influences, &c., are much more likely to affect the young worker.

The physical and psychological qualities which make for proficiency will hardly get a clear field in which to make themselves felt until the novelty and excitement of factory life have ceased to stimulate. When the worker has passed the age at which enthusiasm plays a leading part and has settled down into the humdrum existence of factory life, we may expect that this proficiency then will depend almost entirely upon whether they are well or ill adapted to their work.

If we are to go further in determining the factors which make or mar efficiency, we must endeavour to find out which are the strongest stimulants to work, at various ages. If general factors such as enthusiasm and energy are found to play the chief part in making for proficiency in the young, then we ought to be on our guard lest this enthusiasm be used in the wrong direction.

It might be that a young worker would do almost equally well in any department if he were endowed with this quality, but we must think of his future life when he will be more dependent on real adaptability to the work in question than upon his youthful energy. Vocational guidance, if it is to play a helpful part in industry, must take a very long view, and it should be realised that the work of those engaged in it is not to get immediate results, but to see that the whole life of a worker be used to the best advantage, both for himself and the community, and not, as is too often the case, that his young energy should be sapped up in an occupation he is not really fitted for.

It is not claimed that the results arrived at can do anything more than suggest further lines of research. It may be that after further experiments, physical measurements may be dropped in favour of purely psychological methods of determining fitness for work, but for the present it seems worth while to continue along both lines of investigation. We may find that physical adaptability may in some cases make up for psychological drawbacks, in which case they could be given a certain value in any final test for an occupation.

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By P. M. ELTON, M.Sc.

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PREFATORY NOTE.

The process of silk weaving has already received some attention on the part of the Board, and a report* by Mr P M. Elton, M Sc. (at that time an Investigator to the Board), was published in August, 1920. The present investigation, which deals with the same process on quite different lines, is also the work of Mr. Elton, and has been carried out independently of the Board for Messrs. Grout & Co., Ltd., Great Yarmouth, through whose generosity this report has been placed at the disposal of the Board, and to whom the Board wish to acknowledge their great indebtedness.

The investigations described in most of the previous reports published by the Board have been based chiefly on "mass" data ; that is to say, inferences have been drawn on the assumption that with a sufficient number of observations, chance irregularities such as those due to the personality of a particular worker will tend to cancel one another, and that the results will in fact represent actuality.

In one important section of the Board's work this procedure is at present impracticable. The *method* of doing work is so much a personal characteristic that progress can only be attained through the intensive study of the individual. The part played by the worker himself has doubtless as important a bearing on his fatigue and efficiency as the impersonal factors of his environment. This has already long been realised in the United States, and in this country a proof that interest is now awakening is shown by the formation of the National Institute of Industrial Psychology, a self-supporting organisation formed to study and give effect to these principles.

The present Report, which is based throughout on the second of these methods of investigation, is divided into two parts. Part I deals with the *extent* of the differences in individual performance, and shows that while the performance of any given weaver remains at about the same level for any given quality of cloth, there is no definite line of demarcation between good and bad weavers, the two classes merging into one another by insensible degrees. Further, the large but consistent differences in loom efficiency manifested as between one weaver and another indicate how greatly production in power-loom silk weaving is dependent on the human factor.

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* A Study of Output in Silk Weaving during the Winter Months.—*Industrial Fatigue Research Board Report, No.* 9

(4722) Wt 20840/335/779 1000 2/22 Harrow G. 36

Part II is concerned with the *causes* of the differences of individual performances, investigated by the application of time study. This term has been defined by Farmer as follows :—*

> " Time study is the study of the time taken to perform each particular operation in an industrial task, and from the data thus obtained, endeavouring to fix the proper time the task as a whole should take."

In the present instance time study has been applied with a different object, viz., to ascertain how far and in what respect individual differences in method are related to efficiency in weaving. Production in weaving clearly depends on the length of time the loom is kept running, or, otherwise expressed, on the rapidity with which any necessary stoppage can be dealt with By means of a full classification of the various causes of stoppage and observation of the methods adopted in each case, some of these methods are shown to be definitely good and others to be definitely bad, indicating the great importance of adequate preliminary training in weaving.

The Report itself is confined to silk weaving, but the Board suggest that the methods adopted and the conclusions drawn are applicable with little modification to power loom weaving in any of the other textile trades. Some work on similar lines has, in fact, already been carried out by the Board in the cotton industry. Wyatt,† for instance, has compared numerically the influence of the human factor on production in various processes, and has shown its importance in the case of fancy weaving. Similarly, Wyatt and Weston‡ have applied time study to investigate the methods of work in bobbin winding, and have indicated means of reducing the amount of unproductive time.

In the consideration of the Report, the Board have received the help of the following Committee, composed partly of representatives of the trade nominated by the Joint Industrial Council for the Silk Industry : — Professor E. L. Collis, M.D , F.R.C.P., Mr. S. Courtauld, Mr. J. Downes, Mr. W. Frost, Miss F. Saward, Mr. J. J. Jackson (H.M. Deputy Chief Inspector of Factories).

The Board are also indebted to Mr. Frank J. Farrell, M.Sc., Managing Director of Messrs. Grout & Co., Ltd., for much valuable guidance.

January, 1922.

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* Time and Motion Study.—*Industrial Fatigue Research Board Report, No.* 14, p. 5.

† "Individual Differences in Output in the Cotton Industry."—*Industrial Fatigue Research Board Report, No* 7.

‡ "Some observations in bobbin-winding."—*Industrial Fatigue Research Board Report, No* 8, *p* 11.

AN ANALYSIS OF THE INDIVIDUAL DIFFERENCES IN THE OUTPUT OF SILK WEAVERS.

By P. M. Elton, M.Sc.

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PART I.—INDIVIDUAL DIFFERENCES IN THE OUTPUT OF SILK WEAVERS.

§ 1.—Introduction.

In a former report* I have shown how the output of silk weavers varied in the winter months, and have suggested reasons to which those variations might be ascribed. That report dealt with mass results or the output of a body of workers, and did not attempt to probe into the more immediate causes of output variation, or deal with the differences in output between one individual and another; in the present paper an endeavour is made to examine more closely the variations in output between one individual and another, and the causes of those variations which are associated with the ability, skill, desire, etc., of the weaver, or, in other words, with the human factor.

Part of the material of this report was obtained from efficiency books (compiled in the manner described in the report cited above), and part by personal observation. At the outset I should like to meet the possible objection that the methods which have been used have taken no account whatever of "quality" of production, which in the manufacture of silk fabrics is of prime importance. The methods themselves did not, but the whole machinery of the works for securing a maximum standard of quality warranted the use of the efficiency books for general or average purposes (Part I of the Report), while, as regards output under personal observation (Part II), to the general discipline of the works was added the presence of the observer, so that the results then obtained represented conditions when cloth of good quality was being manufactured. As "efficiency" comprehends quality as well as quantity, it is necessary to emphasise the fact that "quality" of product has not been overlooked.

§ 2.—Distribution of Efficiencies.

The figures about to be used were compiled in the following manner. The exact time at which the weaving of a warp was commenced was noted, and also the exact time when the weaving of the warp was completed. No allowance was made from the net time taken except in the case of a weaver's absence from the works. The total number of yards of cloth produced from the warp was measured, and from this number, a knowledge of the cloth and the time taken for weaving the cloth, the average rate of production in picks† per minute was obtained. This number, expressed as a fraction of the speed of the loom, also measured in picks per minute, gave the percentage efficiency for the warp.

Each of the rates of production about to be given refers to the weaving of approximately 455 yards of the same quality of

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* A Study of Output in Silk-Weaving during the Winter Months.—*Industrial Fatigue Research Board Report*, No. 9.

† Every time the shuttle is thrown across the loom, a thread is left in the warp shed; the action of the loom in throwing the shuttle is spoken of as *picking*, and each thread left by the shuttle as a *pick*.

cloth. Actually this was a plain cloth made from a raw silk warp with 112 double ends of silk per inch, shot with 72 threads per inch of a high grade highly twisted cotton weft of medium counts. It would be false to give the impression that all the warps concerned were of equally good weaving quality ; such a set of warps would be, in practice, impossible to produce in any textile industry and particularly so in the net silk industry. Generally, however, the variation in the quality of the silk was not of itself sufficient to give rise to the huge variations recorded. The magnitude of the variations in output caused by changing from one kind of silk to another in the same class and in a different class will be indicated later (*see* § 4).

In the case in point all the warps were made from first-class silk, though not all of silk of the same "chop," and it will be seen later that a change from one chop to another in the same class does not cause variations in output of the kind shown in the figures.

All the looms concerned were of the same type (six-box revolving), of the same width and, within the usual practical limits, running at the same speed of 144 picks per minute. Actual measurements showed that this number varied between 142 and 148.

The cloth required two shuttles for its production, the weave being two picks from one shuttle, then two from the next, *i.e.*, what is usually known as a " two and two " weave.

TABLE I.—*Rates of production of different warps on the same kind of cloth.*

Picks per Minute.	No. of Warps.	Picks per Minute.	No. of Warps	Picks per Minute.	No. of Warps.
62	1	91	4	109	5
70	1	92	6	110	6
72	1	93	8	111	7
73	2	94	7	112	1
74	1	95	7	113	1
75	1	96	6	114	3
76	3	97	6	115	11
79	6	98	6	116	6
80	4	99	10	117	3
81	1	100	6	118	3
82	2	101	6	119	2
83	4	102	6	120	2
85	1	103	6	121	1
86	9	104	4	122	4
87	5	105	1	123	4
88	7	106	4	124	1
89	3	107	10	125	3
90	7	108	7	126	1
				130	2

From this table will be clearly seen the huge variations in the rates of production of individual warps met with in practice These variations ranged from a rate of 62 picks per minute, representing an efficiency of 43 per cent. to 130 picks per minute, or 90 per cent. efficiency. Another way of emphasising this difference is to point out that while it took 318 hours to weave the former warp it took only 146 hours to weave the latter. The first weaver's hourly earnings were less than one half of the second weaver's, and from the employer's standpoint the second loom earned over twice as much profit as the first, and also more than twice the sum to meet overhead charges in the same time.

To study further the figures in Table I they have been grouped in ranges of 10 picks. All the warps whose rates of production were 65 or over and less than 75 have been grouped together, all those in the 75–84 ranges, etc.

TABLE II.—*Rates of production of the same kind of cloth arranged in ranges of* 10.

Range	55–64	65–74	75–84	85–94	95–104	105–114	115–124	125–134
No. of warps observed ..	1	5	21	57	63	45	37	6
No of warps given by areas of corresponding normal curve ..	0·9	5·6	21·8	50·0	69·8	54·4	25·8	8·6

Burt* has established the theory (guessed at, of course, before) that, whether one takes native ability or scholastic attainments there is no break in the continuity from extreme idiocy to the highest intelligence, from the complete ignoramus to the most erudite of scholars; and that the incidence of these abilities tends to follow a well-known law—the law of normal distribution. He showed that nature does not fix for us the point that separates mental deficiency from normality. That similar statements in regard to the abilities to weave among weavers and the distribution of those abilities are probably true is evidenced by a study of the following graphs.

* *The Distribution and Relations of Educational Abilities* (P S King & Son)

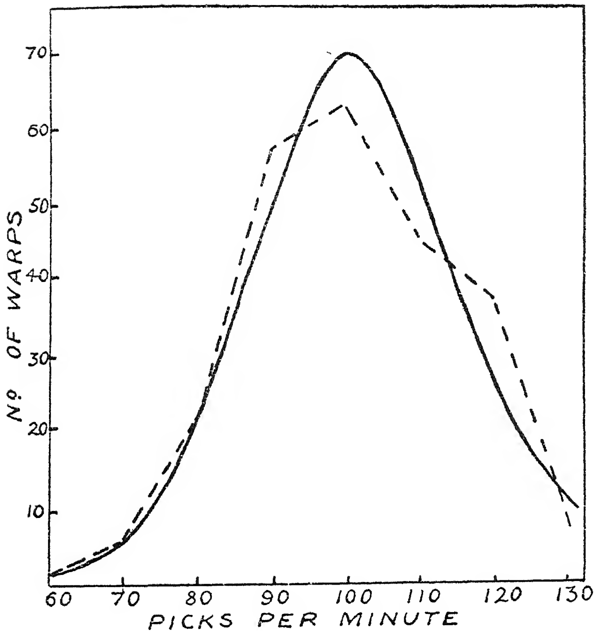

Fig. 1—Graphs showing the figures recorded in Table II.
Broken line=observed series.
Full line=nearest normal or probability curve.

The broken line represents the distribution observed (given by the top row of figures in Table II), and the full line the nearest normal distribution whose areas within the corresponding ranges are given by the lower row of figures in Table II.

Similar distributions of rates of production are shown for four qualities of cloth in Table III.

TABLE III.—*Rates of production in ranges of 10 of several kinds of cloth.*

Quality	Range							
	55–64	65–74	75–84	85–94	95–104	105–114	115–124	125–134
1	1	7	16	56	72	46	22	7
2	1	11	26	48	39	30	7	6
3	8	21	59	153	191	122	84	14
4	4	16	26	54	62	23	18	2

Graphically these distributions are represented in the following curves, each of which approximates fairly closely to a "normal" curve.

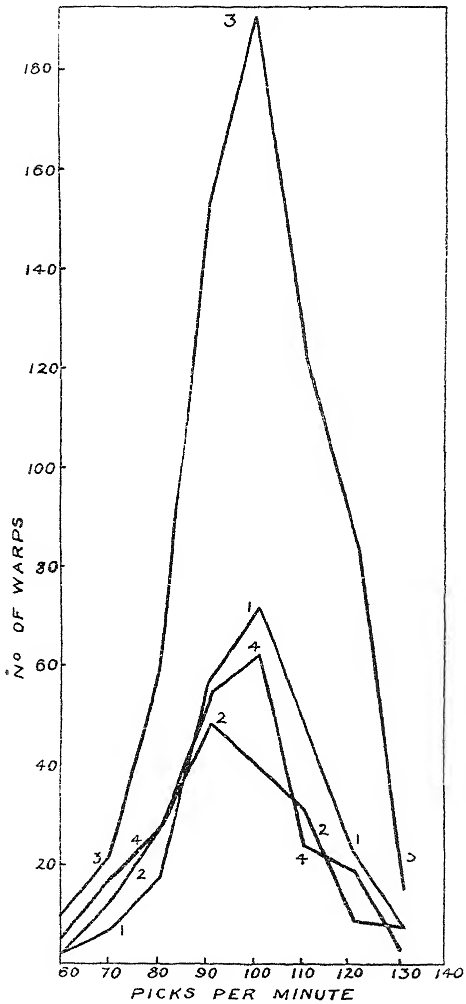

Fig. 2.—Distribution of rates of production in four different qualities of cloth.

§ 3.—Magnitude of the Individual Differences in Output.

On a particular cloth the rates of production of individual weavers are fairly consistent, and when a substantial departure is made from a weaver's average rate of production it may reasonably be inferred that she has had to contend with particularly bad work (or exceptionally good), or that her normal working capacity has been stimulated or depressed. Such stimulation is well known to occur as, for example, prior to a holiday when extra money will be required.

Table IV. shows the rates of production of different warps for twelve weavers (A to L). The looms concerned were all of one type, running at the same speed and making the same kind of cloth.

TABLE IV.—*Rates of production of different weavers on the same kind of cloth.*

Weaver.	Rates of Production of Different Warps.
A.	102, 102, 113, 115, 104.
B.	92, 107, 104, 102.
C.	70, 80, 77, 92, 90, 96, 84, 93, 87, 87, 99, 92.
D.	72, 74, 70, 69, 74, 101, 96
E.	101, 121, 81, 106, 112, 106, 108, 99.
F.	85, 83, 91, 90, 96, 62, 92, 90, 92.
G.	99, 90, 98, 78, 78, 97.
H.	88, 92, 86, 89.
I.	116, 112, 94, 122, 105.
J.	120, 120, 123, 125.
K.	90, 88, 96, 63.
L.	59, 82, 74, 69.

Considering the large number of causes at work which affect output the consistency of these figures, which have been taken at random and have not been specially selected, is remarkable. The general shapes of the distribution curves previously given and the fact that individual weavers give fairly regular rates of production of the same kind of cloth suggest strongly that among weavers the incidence of the ability to weave tends to follow the law of normal distribution, and that there is no absolute line of demarcation between good and bad weavers.

The individual differences in productivity between weavers are again shown clearly in the following table, where records are shown for thirty-two workers, engaged for many months on two looms in weaving the same two qualities of cloth.

TABLE V.—*Comparative productivity of weavers engaged for several months in weaving two qualities of cloth.*

Quality 1.			Quality 2.	
Class. (1)	*Rate of Production.* Per Cent. Efficiency. (2)	Weaver. (3)	*Rate of Production.* Per Cent. Efficiency. (4)	Class. (5)
1	78·0	1	62·5	2
2	73·3	2	68·3	1
4	59·6	3	41·6	4
2	71·1	4	56·3	2
2	74·6	5	70·6	1
1	82·2	6	67·0	1
4	60·6	7	52·7	3
3	67·3	8	59·0	2
4	61·6	9	54·4	3
1	76·5	10	67·6	1
3	64·7	11	52·0	3
2	69·8	12	58·3	2
2	75·0	13	54·6	3
2	70·3	14	58·4	3
3	63·8	15	60·7	2
4	58·9	16	47·3	3
3	63·0	17	52·1	3
2	71·1	18	51·2	3
2	68·8	19	49·7	3
4	61·6	20	51·0	3
2	74·3	21	69·4	1
4	61·5	22	46·3	4
4	60·8	23	54·6	3
3	62·6	24	41·5	4
3	68·5	25	58·5	2
4	55·0	26	50·1	3
3	62·6	27	51·0	3
3	69·0	28	47·4	3
4	57·5	29	51·3	3
3	64·6	30	53·3	3
2	71·5	31	56·5	2
4	60·9	32	39·2	4

The centre column (3) specifies the weaver, columns (2) and (4) indicate the average efficiencies of the weaver on cloths 1 and 2 respectively. Column (1) was obtained in the following manner: the difference was found between the highest and lowest average efficiency on cloth 1, *viz.*, 82·2 and 55·0, and this was divided by 4, giving the following ranges—75·5–82·2, 68·7–75·4, 61·9–68·6, 55·0–61·8. A weaver obtaining an efficiency of 75·5 or over was classified as class 1, 68·7 or over and less than

75·5, as class 2, etc. Similarly the weaver was classified by the position of her rate of production in the range of productivities met with on cloth 2, and the result recorded in column (5). The very close agreement between columns (1) and (5)* confirms the evidence supplied by Table IV, that in power loom silk weaving the amount of production is determined by the weaver.

In the case of hand-loom weaving the importance of the individual is apparent to the most casual observer, and the appearance of a hand-loom weaver is never forgotten. He stands on one foot, for the other is busy depressing the treadle which operates the Jacquard machine; in his right hand is a short stick connected by strings to the pickers, and this hand is always busy throwing and catching the shuttle, the left hand performs wonders, for it works the sley to and fro to beat up the weft, and in addition the fingers and thumb control levers on the sley which work the drop box mechanism and ensure the use of the required shuttle. The weaver's complex co-ordinated movements suggest to an observer immediately the importance of the human factor in hand-loom weaving.

In power-loom weaving the importance of the weaver is not so apparent, but the figures just given and the observations recorded later in this report show clearly that the whole question of production in power-loom weaving is dependent on the abilities of the weaver.

The differences between the rates of production of one individual and another are not constant, but vary with the kind of cloth. These variations are seen in Table VI, in which the number in the column headed "Mean Variation" is a measure of the average variation of the individual values from their average. It is obtained by finding the difference between each rate of production and the average rate of production, adding those differences without regard to sign, and dividing by the total number of rates of production. In the last column headed "Percentage Variation" is a number which enables us to compare one cloth with another as regards the degree of variation in its rates of production. This number is obtained by expressing the "Mean Variation" as a percentage of the corresponding "Average Rate of Production."

* Between columns (2) and (4) the correlation co-efficient is $+\cdot 727$, with a probable error of $\pm \cdot 056$.

TABLE VI.—*Variation in rates of production of different qualities.*

Quality.	No of Warps.	Average Rate of Production.	M.V.	Per Cent. Variation.
A	206	95	11·0	11·6
B	147	97	10·7	11·0
C	81	103	9·3	9·0
D	33	96	7·9	8·2
E	183	85	13·3	15·6
F	47	90	11·4	12·7
G	121	96	11 8	12·3
H	235	100	10·8	10·8
I	59	98	10·7	10·9
J	45	98	10·6	10·8
K	46	104	9·8	9·4
L	81	96	12·3	12·8
M	37	93	11·6	12·5
N	76	103	10·2	10·0
O .. .	75	95	9·5	10·0
P	60	79	8·1	10·3
Q	119	66	11·1	16·8
R	223	67	7·6	11·3
S	214	65	8·1	12·5

Of these nineteen qualities of cloth, fifteen (A to O) were woven in looms running at the same speed, two (P and Q) at a slower speed, and the last (R and S) at a still slower speed.

There is a very general agreement in the figures obtained in the last column, and to say that there was a mean variation of eleven to twelve per cent. among the several weavers in question would not be far wrong. Ready explanations were available in most of the cases where the percentage variation was far removed from eleven. Thus, in the case of quality " D." (where the percentage mean variation was only 8·2), the warp was of cotton, while in every other case net silk was used for warp. As regards " C," (percentage mean variation 9), the silk warp was a coarser thread than usual, being 28–30 denier against threads varying from 13 to 20 denier.* At the other end of the scale there were percentage mean variations of 15·6 and 16·8 in qualities " E " and " Q," where the wefts were comparatively coarse, and, in the case of " Q," difficult to handle, and the operation of reshuttling had consequently to be performed much more frequently than in any of the other qualities.

In the second part of this report will be shown how greatly the times taken for this operation may vary between one weaver and another, and the magnitude of the corresponding variation in the rate of production will be discussed. These figures and the reasons

* The count of net silk is legally " the number of half decigrams in a skein of 450 metres."

advanced for their variation support the view put forward by Wyatt,* that the percentage variation of the rates of production is a measure of the dependence of the process on the human factor. The difference between the meanings to be read into the percentage variation of an average rate of production and the average rate itself is clear. The latter measures, inversely of course, the difficulty of producing a certain kind of cloth, while the former is a measure of the dependence of that difficulty on the abilities of the weavers. Thus, if a coarser weft were substituted for a finer one, such substitution would (if the size of the pirns were kept the same and the number of weft breakages were not altered), necessarily reduce the rate of production, but the mean percentage variation would not necessarily be disturbed because an extra difficulty was added , it is because of the differences in the abilities of the weavers to meet the added difficulty that an increase in the mean percentage variation is to be found.

The average percentage variations in the cotton weavers covered by the report just mentioned* were 6·0 for weavers of plain cloth and 10·0 for weavers of fancy cloth. These numbers should be compared with those in the above table, which give an average percentage variation of 11·6. All the cloths concerned were plain cloths woven with two shuttles, "two and two," and on this class of work the mean variation in rates of production was greater than the corresponding variation in the manufacture of *fancy* cotton goods.

As Wyatt showed that cotton weaving was the least automatic of the cotton manufacturing processes, it is clear that the silk industry is much more dependent on the human factor for success than is the cotton industry.

This question has been investigated further by finding the earnings of each of 125 weavers for a period of twelve months. Each weaver attended two looms, and no weaver had less than three years experience in weaving. In this case the percentage variation found was 16·5, considerably higher than the corresponding average figure found from the efficiency numbers. This divergence is explained by the fact that the wages included two bonuses, one for quality and another for production. Undoubtedly both helped to swell the good weaver's wages, and hence tended to enlarge the percentage variation.

§ 4.—Variations in Output caused by Differences in the Quality of the Warp Silk.

This section is introduced mainly to show how the rate of production of the individual may be affected by a change in the raw material.

* Individual Differences in Output in the Cotton Industry.—*Industrial Fatigue Research Board Report*, No. 7.

The word *quality* in the title is used in a very special sense, for it associates with each chop of silk a definite weaving quality and ignores the variations of the weaving quality among the several bales and skeins of the same chop. The figures given for any chop, however, are restricted to the delivery in a particular season.

TABLE VII.—*Comparison of efficiencies obtained from different kinds of silk.*

Cloth.	Kind of Silk.	No. of Warps.	Average Efficiency.*
1	A	122	68
	B	107	66
	C	42	67
2	D	23	67
	E	10	67
	F	41	68
	G	30	71
	H	13	69
3	I	121	67
	J	35	53
4	K	47	71
	L	53	75
5	M	55	69
	N	41	77
	O	15	58

The eight silks "A" to "H" from which the cloths 1 and 2 were manufactured were all first-class quality "G," being recognised as slightly better than the others, and the quality is reflected in the efficiencies obtained. For cloth 3 two qualities of silk were used, one first-class and the other distinctly third-class. In cloths 4 and 5 the differences in rates of production between warps made from the first-class silks ("L" and "N") and warps made from third-class silks ("K" and "M"), while not negligible, is not so marked as in the case of cloth 3. The reason for this difference probably lies in the fact that cloth 3 was made of a fine silk in a fine reed, while 4 and 5 were cloths made of coarse silk and in coarse reeds. Silk "O" was a very low grade silk.

Multiplication of the examples given would serve no useful purpose; sufficient has been shown to indicate the variations in output which may be caused by changing from one silk to another. From such figures as those quoted it becomes possible for manu-

* Little has been published in regard to the actual rates of production which are achieved in silk manufacturing. Chittick, writing from a large American experience on efficiency standards in manufacturing, in his book "Silk Manufacturing and its Problems," states. "In the manufacture of plain, or simply constructed, broad silks, an output of 65 to 70 per cent. of the theoretical production is considered good practice, the theoretical production being the number of picks that the loom could beat in a given time if running without a stop."

facturers to estimate closely the value to them of high and low priced silks in different kinds of cloth. Thus, in the case of cloth 3 the use of a low grade of silk would only be justifiable if such silk could be bought at a very low figure, whereas in cloths 4 and 5 the use of a high-grade silk would only be justifiable if its cost was approximately the same as that of a much lower grade of silk. The figures are also valuable to the weaver in that they indicate the necessity for adjustments of the rates of wages in accordance with the class of silk being used.

PART II.—SOME OF THE CAUSES OF THE DIFFERENCES IN PRODUCTIVITY AMONG SILK WEAVERS.

§ 5.—General Nature of the Problem to be Studied.

The fact that certain weavers produce more and often better cloth than others might, it was seen, be due to several causes, such as:—

(i) their adoption of better methods.

(ii) their greater dexterity in the use of equally good methods'

(iii) their greater powers of resistance to the oncoming of fatigue (A and B might be equally good workers at their best, but A's strength might last while B tired).

(iv) the differences in their abilities to stick to their work.

(v) circumstances over which the individual worker had no control, *e g.*, variations in the working positions as regards lighting, temperature, air currents, etc., variations in the mechanical states of the looms, etc.

With a view to finding the methods used by the best weavers in performing the several operations involved in the production of cloth, and in the hope of developing a method which might lead to a better understanding of the effects on weavers of fatigue, and of working in different conditions of the atmosphere, or under different conditions as regards light, it was decided to observe closely (1) what weavers do, (2) how they do it, and (3) how long they take to do it. In other words I decided to (1) analyse the workers' task into its component operations, (2) observe how different workers performed each particular necessary operation, and (3) measure the times taken by different persons to perform the several operations. As mere dexterity might well be defeated by the adoption of poor methods, obviously the measurement of the times taken by several weavers to perform the same operation would not by itself throw much light on the problems at issue.

Two methods of work presented themselves. The observer could either endeavour to study the movements of the worker during the whole period of observation, or he could concentrate on the work she did during the stoppage of one or both of her looms. The second course was adopted as being likely to lead to more definite results and also as being within the powers of an observer. Further, although much of the weaver's work which is done while both her looms are running is doubtless of great importance (the report throughout deals with two-loom weavers making cloth on tappet looms), yet it is mainly in the abilities of weavers to shorten the times of necessary stoppages that the differences between their productive abilities lie.

§ 6.—Analysis of the usual Causes of Stoppage of a Plain Loom and of the Work done by the Weaver during such Stoppages.

The form used for collecting the records, which contained the same headings as Table B, p. 32, largely explains itself and represents the divisions into which the weaver's work was analysed before commencing to make observations. It was not designed to cover every possible cause of a loom stoppage as the number of such causes is very great, and the inclusion of many minor (*i e*, occurring very seldom) items might have made the useful application of the analysis impossible. Nor did the analysis pretend to show the only possible method of subdivision of the weaver's work. Alternative subdivisions will doubtless suggest themselves to those with a knowledge of weaving, and some alternatives will be mentioned in what follows.

Apart from the selection of subdivisions, their classification was again a matter of choice. Thus, while one of the principal divisions of the form was headed "*Picking out*," it will be seen that most of the subdivisions thereunder might have been put under the two previous divisions: "*Warp*" and "*Weft*." The arrangement actually made had the advantage of separating more usual occurrences from operations which have to be performed less frequently, and was found after several trials to work satisfactorily. Some explanation of the precise meanings of the various subdivisions is perhaps desirable.

Weft.

Under the heading weft there are two main branches. The first branch contains four subdivisions specifying the four possible sets of occurrences, one of which must precede the restarting of the loom when stopped at the *end of a pirn*. These four arise from the natural consequences of two possibilities.:—

(*a*) either the weaver will herself stop the loom just before the pirn is woven off (this is spoken of as "catching the shuttle"), or

(*b*) the loom will be stopped automatically by the weft fork motion when the pirn is completely woven off.

In either case before the loom is restarted a new supply of weft must be provided, and this may be done in two ways:—

(i) either by using a spare shuttle containing a pirn placed in position and with its yarn threaded through the shuttle eye or

(ii) by refilling the empty shuttle with a new pirn.

Under the second branch (columns (5), (6), (7)) are indicated the three different possible occurrences succeeding a *breakage of the weft*. After any necessary picking out of weft, adjusting the cloth fell to touch the reed, and finding the pick, the weaver may

restart her loom with the pirn in the same shuttle, with a new pirn in the same shuttle, or with a pirn ready threaded in a spare shuttle.

Warp.

Under this heading the two principal branches are "Breakages repaired" and "Straightening up."

Breakages repaired.—In this branch, three subdivisions were made. The first of these covered a repair carried out entirely from the *front* of the loom.

As regards a repair carried out at the *back* of the loom, there are two possibilities:—

(*a*) the weaver may either effect a temporary repair at the front of the loom, then restart the loom and afterwards walk round to the back of the loom and complete the repair, or

(*b*) she may dispense with the temporary work and make a complete repair before restarting the loom.

These subdivisions were found to be of much importance, and, in any further work of this kind, I should make a fourth subdivision by separating from column (8) all the thread breakages which occur at the front of the healds, or between the healds and the cloth fell, and do not give rise to the possibility of a weaver's going to the back of the loom to repair the broken thread.

There is a little ambiguity in the heading of column (9), but the column was intended for the cases where part of the repair was effected at the back of the loom when the loom was running. It was found that one of the differences between good and poor weavers was shown by the regularity with which the observations of their actions in repairing warp breakages fell into columns (8), (9) and (10) respectively. The actions covered by column (9) involve less loss of time than those covered by column (8), as in the former knots are tied when the loom is running, and in the latter when the loom is stopped. If observations taken on a weaver fell regularly in column (10), the weaver could at once be put down as a producer of less than first-class speed. This (and the point needs strong emphasis) does not mean that the weaver is lazy, for the actions covered by columns (9) and (10) are the same, but in one case (column (10)) the weaver goes to the back of the loom to complete the repair before restarting the loom, whereas in the other case (column (9)) the weaver goes round to the back of the loom while it is producing cloth either before stopping the loom or (and this is better from a quality standpoint) after restarting the loom.

Straightening up.—This is an expression coined to cover many little tasks performed on the warp by the weaver. Thus, it embraces

stoppage of the loom to enable the weaver to cut off the long ends of a knot made by a careless winder or warper, or to break out a nib or thick place in the silk and remake the broken thread, or to clean the fluff from the warp which, on certain softer silks, forms on the porry where the threads cross at the extremity of the shed.

Picking Out.

It has already been pointed out that some of the subdivisions under this heading (columns 13 to 16) might have been classified in "*Weft*" and "*Warp*"; on the other hand, often strands of weft have to be picked out when the shuttle is not caught (columns (3) and (4)) and when the weft breaks (columns (5), (6) and (7)). Generally, however, the picking out in these cases is a minor matter as compared with the picking out necessary by reason of the causes named in the several subdivisions under the title "*Picking Out.*" Column (17), (*Bad Start*) implies that a weaver has, after a stoppage, made some mistake, such as, for example, releasing the woven cloth too much or too little and making a bad thick or thin place, the removal of which she has considered necessary.

Weaver.

Columns (19) and (20) need little comment. Obviously when both looms are stopped together, one must wait until the other has received attention The ability to choose correctly which loom should receive first attention is a distinguishing mark of a good weaver, but this ability is often affected by the state of completion of a piece of cloth and the proximity of "making-up" time.

§ 7.—Method of Observation.

The analysis form was pinned by drawing pins on to a thin board round the edge of which was pasted a table for converting the number of seconds taken by a loom to make 100 picks, into the corresponding number of picks per minute. After noting the loom numbers and the quality numbers of the cloth thereon, the speed of each loom was carefully measured by finding twice for each loom the time required for making 100 picks. As far as possible the details at the left of the form were recorded. In making the observations the board was held against the side by the left hand in which was held a stop watch, while the right hand also held a stop watch, and a pencil to record the results.

After a considerable amount of practice the taking of observations became comparatively easy. Generally each period of observation lasted one and a half or two hours, after which the loom speeds were again observed, and all the details on the form completely recorded. The form was divided into

two portions by a horizontal line, and the observations on the two looms were kept separate, those above the horizontal line belonging to the loom whose particulars were recorded to the left of the vertical line in the left-hand column of the form.

The original form contained a space for the percentage loss on each loom during the period of observation (*see* Table A), but this is a quantity to which little importance need be attached. The observation period was also divided into twenty-minute periods by means of broken horizontal lines. This was found to be useful as an aid in recalling actual occurrences on which there was but little opportunity to make notes at the loom.

§ 8.—A Summary of Typical Analyses.

In Tables A and B (page 31) are summarised the observations of the loom stoppages of typical weavers. Considerations of space forbid the publication of each analysis in full, but more detailed figures are, where necessary, quoted in the report itself. The actual records contain a considerable amount of useful information which cannot be reproduced in summarised form.

§ 9.—Notes on Observations of the Work of Individual Weavers.

(*a*) *A Good Weaver* (IP).

The first summary is that of the work of a very competent weaver engaged on the production of two cloths of a widely different character. Each cloth had a net silk warp, the silk being of a very good quality, but whereas quality " CIIM " was shot with about 30 picks per inch of a coarse weft, quality " CHAA " contained 70 picks per inch of a medium counts weft. Both cloths were woven with two shuttles, but while in loom " A " both shuttles contained the same kind of weft, in loom " B " the wefts used in the two shuttles were different. Because of this difference there was much more freedom on changing the shuttle in the making of " CIIM " than in the making of the second cloth, as the spare shuttle (*see* p. 25) could be substituted for either one or the other shuttles on one of them becoming empty. In making the second cloth the weaver rightly used two shuttles only, and did not attempt to use spare shuttles, thus avoiding all risk of wrongly mixing the weft.

The noticeable feature of this collection of figures is the fact that in the whole of the two hours during which, neglecting for the moment the weft breakages, fifty-five pirns were emptied, the weaver never once failed to catch the shuttle. This fact, as will be seen later, saved much time.

The detailed observations falling in columns (1) and (2) showed also how regular the weaver's movements were—on loom " A "

the variation in the times taken was very small, but on "B" the variation was greater.† This was to be expected, for the number of operations covered by column (2) is greater than the number covered by column (1), the weaver having to

(*a*) Stop the loom and take the shuttle out of the shuttle box.
(*b*) Lift up the shuttle peg and remove the almost empty pirn from the peg(*).
(*c*) Place a full pirn on the peg and press the latter down again.
(*d*) Pass the thread from the new pirn through the shuttle eye.
(*e*) Push the shuttle back into the box and restart the loom.

Generally on reaching the operation marked (*) the weaver pulled the small amount of weft off the pirn, leaving the shuttle threaded while the new pirn was placed on the peg. Then the end of the weft on the new pirn was tied or twisted to the old thread and pulled through the shuttle eye. Otherwise the shuttle eye was threaded by passing a double piece of fine wire through the shuttle eye, passing the end of the weft through the double wire and drawing it through the shuttle eye Where the weaver accidently unthreaded the shuttle and had to resort to using a wire the time required rose to 15·0, 16·0, 16·6 seconds. A smaller increase to 13·4 seconds occurred when the shuttle was not pushed quite far enough into the box at the first attempt and a second push had to be given. It should be observed that shuttle kissing, as practised in the Lancashire cotton mills, is unknown in the silk industry.

The second feature is the rapidity with which this weaver repaired the weft breakages (columns 5 to 7). The times taken for the weft breakages vary greatly on two-shuttle work of the kind under observation, for the number of operations which a weaver has to perform when the weft breaks differs according to the position in the cloth fell of the end of the broken thread, the pick on which the breakage occurs, and whether the shuttle is unthreaded or otherwise.

Thirdly, the figures in columns (8), (9) and (10) relating to warp breakages show clearly the sterling qualities of this weaver on the work in question. Of the five stoppages for repairing breakages at the front of the loom, four occurred behind the

† The variations, as calculated from the original data, can be expressed numerically as follows :—

——	Loom A.		Loom B
	1st set	2nd set.	
No. of obervations	44	19	11
Mean time taken (sec)	4·9	4·8	12·9
Mean variation	0·33	0·32	1·7
Percentage mean variation	6·7		13·2

healds, or, what amounted to the same thing, the particular eye in the heald concerned became unthreaded and the threads were repaired by the weaver

(*a*) leaning over the loom frame, finding the broken end and tying it to a length of silk from a spare bobbin suspended just behind the top of the loom frame,

(*b*) finding the vacant eye in the healds and passing the silk through it,

(*c*) finding the corresponding space in the reed and passing the silk through that space,

(*d*) pinning the end down on to the woven cloth and restarting the loom.

A fifth breakage, which took only 15·8 seconds to repair, occurred between the healds and the cloth fell, and the eye of the heald through which the broken thread passed was not unthreaded. Thus there was no need for operations (*a*) and (*b*) outlined above, and the result was a considerable reduction in the time taken to repair the breakage.

As regards column (9) each breakage concerned occurred behind the healds, and the repair was effected in one of two ways, according to whether the weaver was at the front or the back of the loom when she noticed that an end of the warp had broken. If she noticed the broken end at the front of the loom, the weaver leaned over the loom frame, took hold of the end of the thread on a spare bobbin suspended from the loom frame and then went through operations numbered (*b*), (*c*) and (*d*) above. *After* restarting the loom she walked round to the back thereof, found the broken end, broke a length of thread off the spare bobbin, and tied the two ends together.

If she noticed the breakage when at the back of the loom, the weaver found the broken end and tied the end of the thread of the spare bobbin thereto, went round to the front of the loom and stopped it, and then went through all the operations just outlined in the case where the breakage is noticed at the front up to restarting the loom.

In the actual analysis under discussion it will be seen that the weaver concerned went to the back of the loom while it was stopped for the purpose of repairing a warp breakage on only one occasion. She had no chance to do otherwise on that occasion as five ends were broken at the same time, and it was much easier to avoid crossing the ends in the warp by going to the back of the loom; also the loom carried two spare bobbins only.

As regards the 6·2 seconds in column (11), the loom was stopped for this time to enable the weaver to cut off a long end on a knot, the weaver fearing a " bind " might be made.

In column (19) of the detailed analysis were two entries of 50·0 and 62·2 seconds. In neither case was the saving of time advisable, although possible in the former. Just before the weaver had stopped the loom " B " before completing a repair which

took 20·4 seconds, she noticed that one of the shuttles in loom " A " was nearly empty. She had to get the repair completed quickly or the loom would have continued weaving with a warp end out, and if the pirn on loom " A " had become empty while she was engaged on loom " B " she might have had a considerable amount of picking out, involving a fairly long stoppage. Consequently she stopped loom " A," completed the repair on loom " B," then returned to change the shuttle in loom " A " and restarted the loom. A poor weaver might have gone round to the back of loom " B " to complete the repair while the loom was idle and have failed to notice that one of the shuttles in " A " was nearly empty.

In column (21) 10·6 and 6·0 seconds were taken by the weaver in making a bar heading at the end of a piece and 324 seconds taken in removing the cloth, over 90 yards, from the cloth roller.

(b) A Steady Weaver using Bad Methods (1E).

This example has been chosen out of a host of others because the record is not complicated by minor occurrences and is directly comparable with the previous example, the cloths being of the same qualities, the looms exactly similar, and the times of the day when the records were taken nearly the same. The speed of the looms concerned was about 12 picks a minute less than in the former case

The first noticeable weakness in this case was the failure to use a spare shuttle on loom " D " As a direct result of this all the times taken for reshuttling fell in columns (2) and (4). Thus, at 29 reshuttlings after " catching the shuttle " on loom " D " no less than 524·6 seconds were lost ; these results give an average of 18·1 seconds lost at the end of each pirn when the shuttle was caught against a corresponding average of 4·9 seconds in the case of weaver 1P. The following calculation shows how the difference found was affecting efficiency:—

Each of the particular pirns used on the cloth in question was sufficient on the average taken from 403 pirns to make 347 picks in the cloth Had each girl been on a loom running at 144 picks a minute and ignoring all other stoppages, the first loom would have run for 347 picks and then have stopped for $\frac{144 \times 4 \cdot 9}{60}$ $(=11 \cdot 8)$ picks, the efficiency being $\frac{34{,}700}{347+11 \cdot 8}$ per cent. $(=96 \cdot 7)$. The second, after running for 347 picks, would have stopped for $\frac{144 \times 18 \cdot 1}{60}$ picks $(=43 \cdot 4)$, the efficiency in this case being $\frac{34{,}700}{347+43 \cdot 4}$ per cent. $(=88 \cdot 9)$.

Clearly the first weaver had a great advantage over the second, not only as regards output, but also in the ease with which she was

enabled to perform her work. Thus she refilled her spare shuttle leisurely (not lazily) while her looms were running, while the second weaver, filling the shuttle when the loom was stopped, felt it necessary to rush the work so as to get her loom working again.

Returning to the analysis form 1E, column (4) shows that the weaver failed on two occasions to catch the shuttle. Both these failures occurred in connection with a long stoppage of 211·2 seconds to repair three ends on loom " D," and need not be considered seriously. Neither is much to be learned from columns (5) and (7) except that the figures confirm the impression gained by comparing columns (2) (loom " C ") of this analysis with column (2) (loom " B ") of the previous case, that the present girl is slow in her movements as compared with the first.

A really outstanding feature was the large number of entries in column (10). Had weaver 1P been on this loom at least four of these entries would have been in column (9). The non-use of a spare shuttle might perhaps, by itself, have been put down to mere indifference on the part of the weaver, but the manner in which warp repairs were effected showed that her methods, probably due to faulty training, were not good.

Column (11) contains several entries caused by the weaver stopping her loom to help the warp through the reed. Apparently there had been trouble in the warping of the warp, for there were many knots thereon. The entry in column (19) is to the credit of this weaver who saw that two shuttles on different looms were becoming empty together and stopped both the looms, thus probably saving time and the trouble of " picking out," which might have followed her allowing the pirn to empty in the loom.

Because of the regularity with which this girl caught the shuttle, the regular method (although wrong) in which she repaired the warp breakages, and the entries in columns (11) and (19), I have characterised this weaver " steady."

(*c*) *A Poor Weaver* (1*C*).

The third analysis presented in Table " B " shows the work performed by a poor weaver. It is comparable with the two analyses previously given, although on loom " E " the cloth (quality " CHZS ") was less difficult to weave than the cloth of quality " CHAA," which was woven on looms " B " and " C," the count of the warp being coarser, the reed coarser, the weft finer, and the cloth being woven with one shuttle only. The time of observation in all three cases was in the middle of the afternoon, the works' hours being from 2 p.m. to 6 p.m.

The figures in column (1) show that the weaver was much slower in her movements than weaver 1P.

Column (2), loom " F," is curious, for the weaver used a spare shuttle, and at first sight it would appear that the

entry of figures in column (2) was an error on the part of the observer, but such, however, was not the case. It so happened that the weaver had both shuttles coming empty about the same time, and instead of altering this state of affairs by half weaving a pirn and then changing the remaining half for a full one, she continued to change both shuttles during one stoppage, using the spare shuttle to replace one of them and refilling the other. This made the stoppages very long—42 6, 46·8, 38·4 and 45 seconds—because in addition to the weaver's having to refill the second shuttle she had, in order to get it from the loom, to pull the revolving box round with her hand.

Columns (3) and (4) show that she failed to catch the shuttle no fewer than seven times, one such failure resulting in a stoppage of 126·8 seconds.

Little can be remarked about columns (5), (6) and (7), except that the stoppages were much longer than they would have been under a good weaver.

The large number of figures in column (10) shows that this weaver was really inefficient, while the large amount of time spent at the back of loom " E " was responsible for three out of four of the entries, *viz.*, 75, 57 and 94·8 seconds in column (19) loom " F " ; in two cases the weaver stopped loom " F " before going to the back of " E," which was also stopped, and in the third case the pirn on " F " wove off while the weaver was behind "E."

Finally, the detailed observations showed that in removing about 90 yards of cloth from the roller of loom " F " 532·8 seconds were taken, during 414·4 of which loom " E " also was allowed to be idle. Clearly, weaver 1E, though not good, was much better than 1C.

Between weavers 1P and 1C, respectively good and bad at all points, all grades exist, some weavers excelling in a particular phase of the work and failing in other phases—others mediocre only in all phases, etc.

§ 10.—The Personal Character of the Records obtained.

The summaries 2B, 2K and 1P are introduced to show that the general features of the records obtained are determined by the methods of the worker and not by the ease or difficulty of the particular work in hand.

The records for 2K were obtained by observing a near-sighted worker, her defective eyesight probably accounting for the comparatively long time taken for reshuttling and for taking in ends. The long time spent at the back of one loom when that loom was stopped (column (10)) resulted in the frequent failure to catch the shuttle. The records were taken at intervals of five weeks, and are closely comparable.

The analyses for 2B were taken in the morning and afternoon of the same day on a young weaver who found the work almost

too much for her—the same tendencies are observable in both records, frequent failures to catch the shuttle, repairs to ends at the back of the loom with the loom stopped, etc.

Further records taken while the observation form was being developed point to same conclusion, *viz.*, that the record obtained depends on the weaver and not on the work. Thus, further observations taken on weaver 1P after an interval of nine weeks show characteristics similar to those already described in §9 (*a*).

§ 11.—The Connection between Method and Fatigue in Weaving.

Comparison 1.—The analysis 1P and 1C given in §8 afforded a striking example of the effect of weak methods on the amount of work which a poor weaver had to perform. In Table VIII are summarised the principal causes of stoppage of the looms on which weavers 1P and 1C were employed ; in both cases the period of observation was exactly two hours.

TABLE VIII.—*Observed causes of stoppage of the looms of two weavers summarised.*

Weaver	1P			1C		
Loom	A	B	A & B together	E	F	E & F together
Pirns woven off ..	44	11	55	12	26	38[*]
Weft breakages ..	4	4	8	1	2	3
Warp ends broken ..	9	11	20	9	9	18
Piece removed from cloth roller	—	1	1	—	1	1
Other	—	3	3	4	3	7
Total	57	30	87	26	41	67[*]

[*] On four occasions two pirns were changed at one stoppage

From this table it is clear that 1P had a greater number of calls on her energies than had 1C, yet she managed to do more effective work with the expenditure of considerably less energy than that expended by 1C. The ease with which she got the loom going again on a pirn becoming empty was most pronounced, in comparison with the laborious way in which 1C refilled two shuttles at one stoppage, or had to "pick out," release the cloth, and rush to get the loom at work again after failing to catch the shuttle.

In repairing broken ends, 1P, having got her loom at work by means of a temporary repair, walked round conveniently to the back of the loom to complete the job, having time to observe the

other loom, whereas 1C hurried to the back with the loom stopped, and after completing the repair rushed to the front again to restart the loom. Time after time she found that while she had been at the back of one loom the other had pulled up for want of weft, and another quantity of work, performed with the loom stopped and hence under greater pressure than work done when the loom was running, awaited her.

Because of her being so fully occupied on account of her bad methods she had no time to pick or cut loose ends from the cloth while it was being made, and this work was done while she was removing the cloth from the roller. As the work required attention she failed to notice that the shuttle in "E" was emptying, so that the loom pulled up and stopped for 414·4 seconds, causing the weaver considerable anxiety because both her looms were stopped. (The word anxiety is used deliberately; not in the whole number of weavers observed was one found shirking work.) Weaver 1P had time to pick her cloth before it reached the roller, and hence her unrolling of the cloth from a loom was a simple matter, requiring but little attention; any reason necessitating her stopping the other loom would have been detected at once.

While weaver 1C would probably never have been as quick as 1P, abundant evidence was available to show that her bad methods were responsible for a very large amount of the energy she had to expend, and therefore of the fatigue she experienced.

Comparison 2.—A further comparison between weaver 1N, who adopted better methods, and 1W, who adopted worse, shows the consequent extra work 1W had to perform because of the methods she adopted. Table IX summarises the principal causes of stoppage in each case:—

TABLE IX.—*Observed causes of stoppage of the looms of two weavers summarised.*

Weaver	1N			1W		
Loom	G.	H	G & H together	I	J.	I & J together
Pirns woven off . .	39	14	*53*	12	30	*42*
Weft breakages . .	3	3	*6*	1	2	*3*
Warp ends broken . .	6	2	*8*	4	11	*15*
Binds	—	—	—	1	—	*1*
Other	5	3	*8*	1	2	*3*
Total	53	22	*75*	19	45	*64*

The observations on the better weaver were taken in the middle of the afternoon, those on the poorer in the morning, and the qualities of cloth were the same in each case. Each cloth

required two shuttles containing different wefts for its production, and the use of spare shuttles was inadvisable. So far as equality of conditions is possible for two weavers on different looms, such equality existed, except that the speeds of looms " G " and " H " were a little greater than those of " I " and " J." (Loom " G " must be compared with " J," and " H " with " I.") The observation period was one hour and forty minutes in each case

While 1N was undoubtedly quicker than 1W, much of her superiority was due to the better methods she adopted. The extraordinary rapidity with which she repaired (temporarily) a warp breakage (Table B, col. 9) was due to (*a*) the general quickness of all her actions and (*b*) her method of taking hold of the thread on the spare bobbin before stopping the loom (*see* p 24). Because 1W spent so much time at the back of the looms when they were stopped she was not able to supervise efficiently the running of both looms. Consequently the work she had to do was increased greatly (*see* col. (4), (19) and (13)).

As regards the *bind* which caused a stoppage of 415 seconds (col. (13)), no weaver, however efficient, is always able to prevent a bind from being made; but the weaver adopting good methods and consequently having greater freedom quickly sees that a bind is being made or is about to be made and stops her loom either before the bind lasts many picks, or before it is actually commenced. Consequently she has much less picking out to do than the poor weaver who, on account of her methods, has her attention fixed for long periods.

The freedom of 1N gave her plenty of time in which to take steps to prevent binds from arising. All the short period stoppages in column (11) of 1N occurred through her anxiety to avoid binds. While the whole of the stoppages were not necessary it was apparent to the observer that a less capable weaver would not have had the opportunity to prevent binds which 1W had.

Many parallels to the foregoing cases where fatigue has been the result of work created by the use of wrong methods have come to the observer's notice.

Generally, in the weaving of a particular piece of cloth, the better weaver uses less energy than the poorer and consequently her earning power per unit of energy expended is greater. † This does not necessarily mean that a good weaver is less fatigued at the end of the day than a poor weaver, for fatigue is not to be measured in terms of work performed and is not distributed between workers in the ratio of the work they do, whether necessary or unnecessary. If, however, a poor weaver improves her methods and quickens her movements, the inevitable results follow that the work required of her per unit of output decreases, and that any fatigue she experiences will arise through effective work.

† The same difference between a good and a poor worker has been noted by Farmer in the case of metal polishing (Motion Study in Metal Polishing, *Industrial Fatigue Research Board, Report No 15*)

TABLE A.—*Summary of Analyses.—*
Weavers, Looms, Cloths under and Times of Observation

Weaver.	Loom	Quality of Cloth.	No. of Spare Shuttles.	Speed of Loom Picks (per min)	Time of Observation. From	Time of Observation. To	Percentage Loss.
1P	A	CIIM	1	147	2.47	4 47	9·2
	B	CHAA	—	144	2.47	4 47	15·5
1E	C	CHAA	—	132	3 45	5 25	3·3
	D	CIIM	—	132	3.45	5 25	20·6
1C	E	CHZS	1	133	3 0	5 0	18·2
	F	CIIM	1	123	3 0	5.0	27·1
2K	M	CIIM	1	144	2 44	4.24	23·4
	N	ZZZ	1	148	2 44	4.24	45·7
2K	M	CIIM	1	148	9 20	11 20	24·9
	N	XXZ	1	148	9 20	11 20	10·4
2B	K	HHIA	2	147	9 32	11 12	13·2
	L	CHAA	2	148	9 32	11 12	23·2
2B	K	HHIA	—	147	3 54	4 54	24·4
	L	CHAA	—	148	3 54	4 54	24·5
1P	A	CIIM	1	145	10 40	11 40	—
	B	—	—	—	—	—	—
1W	I	CHAA	—	119	10.13	11 53	18·4
	J	HHXX	—	129	10.13	11 53	24·3
1N	G	HHXX	—	136	3.2	4 42	10·0
	H	CHAA	—	123	3.2	4 42	6·3

Weaver	Loom
1P	A
	B
1E	C
	D
1C	E
	F
2K	M
	N
2K	M
	N
2B	K
	L
2B	K
	L
1P	A
	B
1W	I
	J
1N	G
	H

TABLE B.—*Summary of Observations.—Causes, Number and Duration of Stoppages.*

Weaver	Loom	Stoppages	WEFT.							WARP.					PICKING OUT.						WEAVER.		Loom Mechanism Other
			End of Pirn.				Breakage.			Breakage Repaired			Straightening Up		Warp		Weft		Bad Start	Other	Engaged on other Loom	Away from Looms	
			Shuttle caught		Shuttle not caught		Re-start on same pirn	Spare used	Same used New pirn.	Front of Loom	Back of Loom		Front of Loom	Back of Loom	Bind	Ends Down	Wrong Twist	Snarls					
			Spare used	Same used	Spare used	Same used					After re-starting	Before re-starting											
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)*	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
1P	A	Number ..	44	—	—	—	2	—	2	2^{2}	5^{7}	—	—	—	—	—	—	—	—	—	2	—	—
		Average length..	*4·9*	—	—	—	*15 0*	—	*15·0*	*31·5*	*28·7*	—	—	—	—	—	—	—	—	—	*56·1*	—	—
	B	Number ..	—	11	—	—	1	—	3	3^{3}	3^{3}	1^{5}	1	—	—	—	—	—	—	—	—	—	3
		Average length..	—	*12 9*	—	—	*17 2*	—	*38·5*	*35·3*	*17·8*	*327·4*	*6·2*	—	—	—	—	—	—	—	—	—	*113 5*
1E	C	Number ..	—	12	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		Average length .	—	*11 3*	—	*26·2*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	D	Number ..	—	29	—	1	1	—	1	1^{1}	—	5^{7}	6	—	—	—	—	—	—	—	1	—	—
		Average length .	—	*18·1*	—	*45·8*	*53 4*	—	*44·6*	*37·4*	—	*86·2*	*12 3*	—	—	—	—	—	—	—	*24·0*	—	—
1C	E	Number ..	8	—	4	—	1	—	—	1^{1}	—	6^{8}	—	1	—	—	—	—	—	—	—	—	4
		Average length..	*8·5*	—	*23·1*	—	*50·6*	—	—	*31·0*	—	*99 1*	—	*32·8*	—	—	—	—	—	—	—	—	*109·4*
	F	Number .	15	4	2	1	—	2	—	2^{2}	—	6^{7}	1	2	—	—	—	—	—	—	4	1	—
		Average length.	*8·1*	*48·2*	*38·2*	*126·8*	—	*84·3*	—	*27·5*	—	*74·8*	*8·2*	*8·1*	—	—	—	—	—	—	*189·9*	*202 6*	—
2K	M	Number ..	34	—	6	—	—	—	—	—	2^{2}	5^{6}	5	1	1	—	—	—	—	—	3	—	—
		Average length .	*7·0*	—	*36·7*	—	—	—	—	—	*31·9*	*79·3*	*11·0*	*60 0*	*77·6*	—	—	—	—	—	*98 0*	—	—
	N	Number ..	—	2	—	—	—	—	2	2	—	8^{17}	—	—	—	—	—	—	—	—	2	—	2
		Average length..	—	*16 7*	—	—	—	—	*44·8*	*49·4*	—	*120·9*	—	—	—	—	—	—	—	—	*31·0*	—	*713 1*
2K	M	Number .	36	—	3	—	3	1	—	4^{6}	—	3^{5}	4	—	2	—	—	—	—	—	—	—	4
		Average length	*7·4*	—	*54·3*	—	*60 6*	*50·6*	—	*59·2*	—	*89·9*	*9·2*	—	*223·7*	—	—	—	—	—	—	—	*30 2*
	N	Number ..	2	—	1	—	—	5	—	2^{2}	—	3^{3}	—	—	—	—	—	—	—	—	—	—	1
		Average length	*6·5*	—	*18·6*	—	—	*61·1*	—	*40 3*	—	*69·0*	—	—	—	—	—	—	—	—	—	—	*121 2*
2B	K	Number .	31	—	9	—	3	4	—	2^{2}	—	—	1	—	—	—	—	—	1	—	—	—	—
		Average length .	*5·9*	—	*19·1*	—	*41 3*	*33·1*	—	*39 1*	—	—	*7 0*	—	—	—	—	—	*95 0*	—	—	—	—
	L	Number ..	6	—	6	—	1	1	—	5^{5}	—	3^{5}	4	1	1	—	—	—	—	—	2	—	—
		Average length .	*5·8*	—	*23·8*	—	*100 1*	*27·0*	—	*50·4*	—	*104·6*	*9·9*	*106 8*	*285 0*	—	—	—	—	—	*19·0*	—	—
2B	K	Number ..	14	—	5	—	2	1	—	1^{1}	—	—	2	1	1	—	—	—	—	—	—	—	—
		Average length..	*5·6*	—	*16·2*	—	*58·1*	*34 8*	—	*24·4*	—	—	*12·2*	*56·2*	*462·8*	—	—	—	—	—	—	—	—
	L	Number .	5	—	1	—	—	2	—	4^{4}	—	2^{4}	2	—	—	—	—	—	—	1	2	—	—
		Average length .	*5·0*	—	*55·6*	—	—	*27·0*	—	*26 0*	—	*100·9*	*9 0*	—	—	—	—	—	—	*220 2*	*105·0*	—	—
1P	A	Number	19	—	—	—	—	1	—	2^{2}	4^{5}	—	—	—	—	—	—	—	—	2	—	—	1
		Average length .	*4 8*	—	—	—	—	*18·0*	—	*31·9*	*26·8*	—	—	—	—	—	—	—	—	*7 2*	—	—	*245·0*
	B	Number	Records not taken																				
		Average length .																					
1W	I	Number ..	—	8	—	4	1	—	—	—	—	3^{1}	1	—	1	—	—	—	—	—	4	—	—
		Average length .	—	*13 4*	—	*33·0*	*55·2*	—	—	—	—	*81·4*	*11·4*	—	*415·0*	—	—	—	—	—	*35·0*	—	—
	J	Number .	—	28	—	2	1	—	1	—	1^{1}	7^{10}	1	—	—	—	—	—	—	—	2	—	1
		Average length .	—	*14·0*	—	*42·0*	*73·0*	—	*92 8*	—	*27 6*	*82·7*	*21·8*	—	—	—	—	—	—	—	*90·0*	—	*9·6*
1N	G	Number .	—	38	—	1	2	—	1	1^{1}	5^{5}	—	5	—	—	—	—	—	—	—	—	—	—
		Average length..	—	*9·3*	—	*34·4*	*17·3*	—	*32·4*	*20·6*	*12·8*	—	*11·4*	—	—	—	—	—	—	—	—	—	—
	H	Number ..	—	12	—	2	3	—	—	—	2^{2}	—	3	—	—	—	—	—	—	—	—	—	—
		Average length..	—	*13·4*	—	*37·8*	*28·3*	—	—	—	*15·7*	—	*8·7*	—	—	—	—	—	—	—	—	—	—

* The small figures in Columns 8, 9 and 10, denote the actual number of ends repaired

§ 12.—Maximum Output Obtainable.

If the conclusion is accepted that the output per unit of energy is at its maximum when the best methods are adopted, it becomes of interest to estimate from the observations of the best weavers the optimum output of a loom on a particular kind of cloth. No loom can possibly have an efficiency of 100 per cent. In the most automatic loom a stoppage must be made between the finishing of one warp and the starting of the next; in the ordinary loom shuttles must be replenished and on all looms breakages of warp and weft occur.

For most practical purposes it will be convenient to answer the question, "What fraction is obtainable of the amount of cloth which would be made by a loom working without a stop during engine running hours?" The answer will always be open to criticism, for in a loom of given speed the result will depend on the time allowance made for each kind of necessary stoppage and the number of stoppages considered necessary.

In a mechanically perfect ordinary loom supplied with perfect yarns, no breakages of weft and warp would occur and the only necessary stoppages would be those occurring when the pirns came to an end. The time taken for one reshuttling depends on many circumstances. Williams* has suggested four seconds as the standard time for reshuttling a cotton loom when a spare shuttle was used. The observations I have made show that, while weavers of silk cloths often reshuttle a loom in four seconds and even less, the best seldom reach so low a figure on an average taken over two hours' observation.

Table X gives the times taken for reshuttling, using a spare shuttle, by a number of weavers selected at random. All the figures refer to the same quality of cloth.

In manufacturing a two-shuttle cloth where the shuttles contain weft of the same counts, but twisted in the opposite direction, it is generally considered advisable to use only two shuttles and to make arrangements so that one shuttle will only take weft twisted to the right and the other only weft twisted to the left.† Table XI gives the times taken by certain weavers in reshuttling when no spare was used. The actual times are not given because of the great variation and the necessity for condensing the table, but the correct averages are stated.

The time taken in this operation depends also on the kind of shuttle and the pirn used. All the figures relate to the same types of pirn and shuttle.

Williams has suggested the following standard times :—

(1) 5 seconds for reshuttling.
(2) 30 ,, ,, repairing weft breakages.
(3) 15 ,, ,, repairing warp breakages.

---

* *Textile Manufacturer*, Aug 15th, 1920.

† With cheap cloths, however, it may perhaps be considered wise to risk the wrong mixing of the weft in order to save time at reshuttling. In the border line cases the use or non-use of spare shuttles is often left to the discretion of the weaver.

TABLE X.—*Summary of the duration of loom stoppages during reshuttling—using spare shuttle, and neglecting failures to catch the shuttle.*

Weaver	Period of Observation	Times (seconds) and Number of occasions.																							Number of Reshuttlings	Average Time
		3·6	3·8	4·0	4 2	4 4	4·6	4·8	5 0	5 2	5·4	5 6	5·8	6·0	6·2	6·4	6·6	6·8	7 0	7 2	7·4	7·6	7 8	Other Times		
	mins																									
P	120	4	9	13	6	4	1	2	1	—	2	1	—	2	—	—	—	—	—	—	—	—	—	—	45	4·2
F	75	—	—	—	—	1	3	—	—	—	1	1	2	4	2	—	—	3	—	1	—	—	—	8·8, 10 2, 13 0	21	6 5
G	60	—	—	1	—	1	2	3	—	1	2	2	—	1	1	1	—	—	—	—	—	—	—	—	15	5 2
M	120	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	1	3	4	8	1	2	8·0, 8·0, 8·0, 8·4, 8·8, 9 0, 9·4, 14·2	29	7·8
1P	120	—	1	—	2	2	10	10	9	7	—	1	1	—	—	—	—	1	—	—	—	—	—	—	44	4·9
1S	115	—	—	—	—	—	1	—	3	13	4	5	1	2	1	2	1	—	1	—	1	—	2	9 2	38	5 8
2H	90	1	6	3	9	4	3	2	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	29	4 3
2K	100	—	—	—	—	—	—	—	1	—	—	2	1	4	3	4	1	2	1	4	1	2	1	8·0,8 4,8 4,8 8, 9 0,9 6,9·8	34	7 0
2S	100	—	—	—	—	—	—	—	2	3	4	3	3	5	2	—	3	—	—	—	—	—	—	—	25	5·7

TABLE XI.—*Summary of the duration of loom stoppages during reshuttling—without spare shuttles.*

Weaver.	Period of Observation.	Times (seconds) and Number of occasions																		Number of Reshuttlings	Average Time
		5·6 to 6·5	6·6 to 7·5	7·6 to 8·5	8·6 to 9·5	9·6 to 10·5	10·6 to 11·5	11·6 to 12·5	12·6 to 13·5	13·6 to 14·5	14·6 to 15·5	15·6 to 16·5	16·6 to 17·5	17·6 to 18·5	18·6 to 19·5	19·6 to 20·5	20·6 to 21·5	21·6 to 22·5	Other Times		
2R	90	—	—	—	—	—	1	4	5	3	4	4	2	—	1	1	1	—	—	26	14·7
2F	60	—	—	—	—	1	1	4	6	3	2	2	—	—	1	1	1	1	—	23	14·4
2M	80	—	—	—	—	1	3	8	6	3	2	—	1	—	—	—	—	—	—	24	12·7
2D . ..	100	—	—	—	—	—	—	1	3	11	6	3	3	—	—	—	—	—	23·2, 24·8, 25·2, 25·4	31	15·9
1W . ..	100	—	—	—	—	—	1	7	4	6	4	2	3	1	—	—	—	—	—	28	14·0
1U	120	—	—	—	—	3	13	15	5	2	1	1	—	1	—	—	—	—	26·4	42	12·4
1N	100	1	3	10	10	5	3	4	2	—	—	—	—	—	—	—	—	—	—	38	9·3
1H . ..	73	—	—	—	—	—	2	8	2	3	4	—	—	—	—	—	—	—	23·6	20	13·5
N ..	120	—	—	2	4	2	9	10	3	1	1	1	1	—	—	1	—	—	—	35	11·8
Y	100	—	—	—	4	6	9	7	3	2	—	—	—	—	1	—	—	1	25·0	34	12·1

These times appear too short for the kind of work with which this report deals and the following have been adopted :—

(1) (*a*) 5 seconds for reshuttling when using a spare shuttle
(*b*) 11 ,, ,, reshuttling without using spare shuttle.
(2) 40 ,, ,, repairing weft breakages.
(3) 30 ,, ,, repairing warp breakages.
(4) 5 minutes for taking piece off roller, etc.

The *number* of stoppages are based on averages found by hours of observation on the cloth in question.

The particulars given in Table XII relating to three qualities of cloth were found by observation or from the quality of the cloth.

TABLE XII.—*Calculation of maximum efficiency obtainable.*

(1)	Quality.	CIIM.	CHAA.	HHXX	How Particulars Obtained
(2)	Spare shuttle used..	Yes	No	No	Nature of cloth
(3)	Length piece ..	90 yds	90 yds	65 yds	,, ,,
(4)	Picks per inch ..	32	72	40	,, ,,
(5)	Picks per piece ..	103,680	233,280	93,600	(3) × (4) × 36.
(6)	Picks made under observation	140,040	248,468	362,332	Sum of products (loom speed × net time).
(7)	Pirns used under observation.	403	246	1,172	Observation
(8)	Weft breakages under observation.	24	56	64	,,
(9)	Warp breakages under observation.	99	121	322	,,
(10)	No. of picks per pirn	347	1,010	309	(6) ÷ (7)
(11)	No of picks per weft breakage.	5,835	4,437	3,484	(6) ÷ (8).
(12)	No. of picks per warp breakage.	1,415	2,053	1,125	(6) — (9).
(13)	Pirns per piece .	299	230	303	(5) — (10).
(14)	Weft breakages per piece	17·9	52·6	26·9	(5) ÷ (11)
(15)	Warp breakages per piece.	73·3	113·6	83·2	(5) ÷ (12).
(16)	Loom speed (picks per min)	144	144	132	Usual practice on kind of cloth.
(17)	Net weaving time (mins.).	720	1,620	709	(5) — (16).
(18)	Time for reshuttling	24·9	42·2	55·6	CIIM $\frac{5}{60}$ × (13). CHAA HHXX } $\frac{11}{60}$ × (13).
(19)	Time for weft breakages	11·8	35·1	17·9	$\frac{40}{60}$ × (14).
(20)	Time for warp breakages	36·7	56·8	41·6	$\frac{30}{60}$ × (15)
(21)	Time for taking piece off	5·0	5·0	5·0	
(22)	Total time required	798·4	1759·1	829 1	(17) + (18) + (19) + (20) + (21)
(23)	Optimum efficiency	90·1	92·1	85·5	(17) ÷ (22) × 100.

The figures arrived at in the last column agree well with the best results found in practice, and are presented mainly to show the length of time which a loom must be stopped for necessary

reasons. The optimum efficiency on a particular cloth being fixed by the above methods, it would be a comparatively simple matter to find the optimum efficiency on all similar cloths.

The methods of a weaver who could, on the average, reach, on any of the cloths mentioned in the table above, the efficiency noted in the last line would be extremely good. The best out of hundreds of weavers whose records have been examined attained an average of 83 per cent on "CIIM," 89 per cent. on "CHAA" and 75 per cent. on "HHXX."

§ 13.—Suggested Further Uses of the Stoppage Analysis Form.

In the future more attention will have to be paid to the training of weavers than has been given in the past, and, with the raising of the school leaving age, the selection for training in weaving of only those young persons who are likely to become good weavers will demand serious attention The observations made have already shown that good silk weavers

(1) have good eyesight,
(2) are observant,
(3) are dexterous with both hands,
(4) have a delicate sense of touch,
(5) can stand for long periods.

More subtle powers than those enumerated above will probably emerge from a prolonged series of movement observations, but a young person who has not all these attributes developed to a considerable degree should not be trained to weave. No matter what system of training for young weavers is adopted, whether by tuition by individual weavers in the works or by a teacher in a school, not less than two years will be taken by a girl in learning to weave quickly and well, and it is essential that the time of a girl who can never become a good weaver should not be wasted, and that the employer should not incur expenditure in training such a person. Either in its present or in a modified form there is much room for a continuation of the use of the Loom Stoppage Analysis Form with a view to extending our knowledge of the physiological and psychological qualities of good weavers.

The observations have shown how greatly the methods of individual weavers vary, and how many weavers would have benefited by a good schooling in method. The form of analysis can undoubtedly be used to develop methods of teaching young weavers to produce good cloth quickly.

When commencing the series of observations, I intended to observe the actions of the same people at different hours of the day and in artificial light, but the general slump in the textile trade last year, resulting in reduced working hours, in the stopping of the production of many kinds of cloth and the making of new cloths for fresh markets, prevented this from being done.

Some observations made under artificial light, however, appear to show that the fall in output known to occur in artificial light may be due to deterioration in method, in addition to an increase in the time required for a particular operation. The methods outlined in this report would seem to be capable of development with a view to their being used as detectors of fatigue which may be manifested either by a lengthening of the time required for a particular observation, or by an alteration in method ; and as a rapid means of estimating the effect of various systems of artificial lighting or other conditions of work on the individual.

SUMMARY OF CONCLUSIONS.

1. Among weavers the incidence of their abilities to weave tends to follow the law of normal distribution (pp. 9, 10, 11). The variations in the output of silk weavers are greater than the corresponding variations among cotton weavers (p. 15).

2. Productivity in weaving depends to some extent on the speed with which the weaver performs certain standard operations (*e.g.* reshuttling p. 25), and to a greater extent on the methods which the weaver adopts (pp. 22–27).

3. Large and consistent differences were found in the rates of performing standard operations and in the methods adopted by the weavers (pp. 22–27). The weavers whose methods were not good had a greater amount of work to do per unit of output than those who adopted good methods (pp. 28–32).

4. Much of the useless work a poor weaver has to do arises from lack of, or faulty, training (pp. 26, 27, 30). The setting up of a school for teaching weaving is strongly recommended in all weaving establishments, excepting those which are very small.

5. It is possible to estimate with considerable accuracy the maximum rate of output obtainable on a particular cloth (pp. 36, 37).

6. Further use might be made of the methods outlined in this report, in order to determine the variations of the speed of performing particular operations and of the methods of work of weavers at different hours of the day, under different lighting conditions, etc. (p. 37).

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Milk and its Hygienic Relations. By Janet E. Lane-Claypon, M.D., D.Sc. (Lond.) Price 9s. net [Longmans, Green & Co]

The Amoebae living in Man By Clifford Dobell, F R S Price 7s. 6d net. [Bale, Sons, & Danielsson, Ltd]

The Intestinal Protozoa of Man By Clifford Dobell, F R S, and F. W. O'Connor, M.R.C.S., L R C.P., D T.M, and H. Price 15s. net [Bale, Sons, & Danielsson, Ltd.]

In addition to the publications contained in the list given above, numerous memoirs upon work aided by the Medical Research Council have appeared in Scientific Journals.

PAPERS BASED ON RESULTS OBTAINED FOR THE BOARD AND PUBLISHED IN SCIENTIFIC JOURNALS.

WYATT, S., and WESTON, H. C. (1920) : A fatigue test under industrial conditions.—*Brit. Journ. Psych.*, **10,** Part 4.

MUSCIO, B. (1920) : Fluctuations in Mental Efficiency.—*Ibid.*, **10,** Part 4.

MUSCIO, B. (1921) : Is a fatigue test possible ?—*Ibid.*, **12,** Part 1.

MUSCIO, B. (1921) : Feeling Tone in Industry.—*Ibid.*, **12,** Part 2.

STURT, M. (1921) : A comparison of Speed with Accuracy in the Learning Process.—*Ibid.*, **12,** Part 3.

MEDICAL RESEARCH COUNCIL.

REPORTS OF THE INDUSTRIAL FATIGUE RESEARCH BOARD.

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(Potteries Series No. 1.)

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PREFATORY NOTE

The question of over-heated potters' shops, and particularly the likelihood of ill-effects on health and general fitness arising from back draughts of vitiated air from the drying stoves into those shops, has long engaged the attention of those who have been aiming at improved conditions in the earthenware and china factories.

The position prior to the issue of the Pottery Regulations in 1913, may be indicated by quotations from a lecture* delivered before the Royal Society of Arts (as one of the Shaw lectures on Industrial Hygiene) on 7th February, 1908, by Mr. Wm. Burton, F.C S., the well-known member of the firm of Pilkington's Tile & Pottery Co., Ltd. Referring to statements of H.M. Inspectors of Factories, as they appeared in the Annual Reports of the Chief Inspector, he said :—

> "For some years now these reports have laid great stress on the high temperatures found in pottery workshops and the inadequacy of their ventilation. The usual systems of drying used in the majority of potteries are not very enlightened or scientific. The old idea seemed to be that the drying should be conducted at a high temperature in a confined space, whereas everyone should know that the first principle in such methods is to pass sufficient volumes of dry air, and not necessarily very hot air, over and among the articles to be dried."†

In 1908–10, the Departmental Committee on the Use of Lead and Dangers arising from Dust and Other Causes in Potteries, considered this problem, among others. In their Report‡ they say:—

> "Owing to defective building, there is frequently a constant escape of hot and moist air from the drying stoves into the workrooms,"

and they point out that this is especially found where the stoves are steam-heated They recommended ventilation of all stoves direct to the open air and the provision in adjoining workrooms of wet-bulb thermometers with a prescribed limit of 70° F. on that instrument, except when the wet-bulb reading in the shade in the open air exceeds 65° F This limit was selected, not as necessarily a standard from the point of view of health, but because it was felt that the due observance of this limit would in practice involve the restriction of the back-flow of hot moist air from badly ventilated stoves.

These recommendations were embodied in the Pottery Regulations made by the Home Office in January, 1913, and since then much attention has been paid by H.M. Inspectors of Factories to securing their observance. As time went on (and despite the

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*"The Hygiene of the Pottery Trade" *Journ. Roy. Soc. Arts*, No. 2888.

†The conditions of drying are fully discussed in Part II of the present Report (pp. 57, sqq)

‡Cd 5219, pp 52, sqq

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dislocation of the War intervening) it became increasingly obvious that the construction of many drying-stoves—even new ones—was such as to involve the greatest difficulty in controlling the back draught. The National Council of the Pottery Industry in the early stages of its existence took up this question and appointed a small Sub-Committee which in due course published an Interim Report on the Construction and Ventilation of Drying Stoves This was recognised as only a first contribution and, as many members of the Council felt that more definite facts were needed as a basis for further progress, suggestions were made that an enquiry on physiological lines might be of great help in indicating a means of grading potters' shops (with stoves) in accordance with their relative characteristics, as hygienic workshops or the reverse.

With this object, and especially since it was thought that unhealthy conditions due to hot moist air would necessarily involve fatigue, the National Council, in February, 1920, decided to approach the Industrial Fatigue Research Board and invite their assistance in the further study of this question. This invitation was cordially accepted by the Board, and in due course the investigation was entrusted to Dr. H. M. Vernon, assisted by Mr. T. Bedford.

In accordance with the usual practice of the Board, a special Committee (composed partly of members or nominees of the Board and partly of representatives of the industry, nominated by the Council) was formed for the immediate supervision of the work. This Committee was constituted as follows :—

Dr. T. M. Legge, C.B.E. (*Chairman*). Prof. E. L. Collis, M.D., M.R.C.P. Prof. Winifred Cullis, D.Sc. Miss Mona Wilson, J.P.	Nominated by the Board.
Mr. Joseph Burton. Mr S. Clowes, J.P. Mr. A Hollins. Mr. A. H. Maddock.	Nominated by the National Council.

Mr. E. A. R. Werner, O.B.E. (H.M. Superintending Inspector of Factories).

In addition to the full Committee, a local Sub-Committee, consisting of the industrial representatives and Mr. Werner, was formed to advise the Investigators in the progress of their work.*

The Board hope that as a contribution to a large and difficult problem, the present report will be found to contain facts and figures of interest ; all the more, perhaps, because according to the information of the Board, they tend to modify somewhat radically certain of the views previously accepted as almost axiomatic.

March, 1922.

* Attention is directed to the note by this Sub-Committee printed at the end of this Report. (*See* p 74).

TWO INVESTIGATIONS IN POTTERS' SHOPS.

PART I.—ATMOSPHERIC CONDITIONS IN POTTERS' SHOPS.

By H M. Vernon, M.D., and T. Bedford,
Investigators to the Board.

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Introduction.

It is desirable to determine whether the atmospheric conditions met with in potters' shops compare favourably or unfavourably with those occurring in the workshops of other industries, and with the conditions thought to be most suitable for maintaining the health and efficiency of the workers. The amount of accurate information at present available for purposes of comparison is small, but it is being collected in several industries at the present time, and will become increasingly valuable in proportion to its quantity and range. In the present investigation we made numerous observations on the wet and dry bulb temperature of potters' shops by means of the hygrometer, and on the cooling power of the air by means of the dry kata thermometer. For reasons described by one of us elsewhere (Vernon, 1922), we have made no systematic observations with the wet kata thermometer.

Previous Temperature Observations.

No general agreement has yet been reached concerning the most suitable temperatures at which industrial work should be carried on, though everyone recognises that it should vary to some extent with the character of the work. One American firm (Tarbell, 1916) worked out the following scale of temperatures which were maintained, so far as possible, in its works :—Rooms where men are moderately active and able to move about, 65° to 67° ; foundry, smithshop, and carpenters' shop, where active work is the rule, 55° to 65° ; storage rooms where men are not regularly employed, 40° to 50°. The average temperatures recorded at a number of factories "where complaints are infrequent,"

are stated (*The Organizer*, 1919) to be :—For factories where sedentary work is performed, 58° to 66° ; for those with light labour at machines, 50° to 61° ; for those with heavy labour at machines, 46° to 51° ; and for those with heavy manual labour, 44° to 48°. These latter temperatures are distinctly lower than those recommended by the American firm, and are certainly lower than most industrial workers would approve of. In the recently published Report to the Board on "Atmospheric Conditions in the Boot and Shoe Trade," the investigators (Hambly and Bedford, 1921) suggest a temperature of 65° to 67° for a sedentary operation such as clicking ; one of 60° to 65° for an active operation such as sole-cutting, and one of 55° to 60° for somewhat heavy operations such as lasting and edge-setting

The work of the potter is continuously active, but it is not heavy ; and, as far as can be gathered from the above recorded data, it should be carried out at a temperature of rather over 60°. We think that the mean temperature recommended for the active operation of sole-cutting, viz., 62·5°, should be provisionally accepted as the ideal to be aimed at. It naturally follows that this temperature applies only to seasons of the year when the outdoor temperature is low or moderate. When it is higher than 62·5°, the factory temperature must likewise be higher, but as outdoor temperatures much above 65° are seldom observed, except in the late morning and in the afternoon, and as there is always a considerable delay in the transmission of heat from the air outside to the air inside a substantially built factory, we think that it should be possible, as a rule, to maintain the factory temperature at about 65°, even when the outdoor temperature is 65°. When the outdoor temperature is 70° or more, it should generally be possible to maintain the factory temperature at a somewhat *lower* level than outside, because of the delay in the transmission of external heat. We therefore suggest the following ideal relations between outside and inside temperatures for ordinary factories where active (but not heavy) work, such as that of the potters, is being carried on :—

Outdoor Temperature.	*Factory Temperature.*
60° or less	62·5°
65°	65°
70°	69°
75°	73°

That this ideal is not impossible of attainment, is proved by the observations made by one of us at a large fuse factory of 9,000 workers Temperatures were taken by means of a hygrometer placed near the middle of one shop, 200 ft. square, and by means of a hygrometer and two thermometers placed near the middle and ends of a larger shop, 400 × 180 ft. Readings were taken at about 9 a.m., 12 noon, 3 p m., and 5.45 p.m. on many days during every month from March to July, and in October, 1917, whilst other readings of a hygrometer fixed outside were taken for comparison.

TABLE I.

Comparison of Outdoor and Indoor Temperatures at Fuse Factory.

Temperature Range	Number of Observations	Mean Outdoor Temperature		Mean Temperature in Smaller Shop		Mean Temperature in Larger Shop.	
		Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
		°	°	°	°	°	°
Under 40°..	16	37·1	34 2	61·5	53·5	55·4	48·9
40° to 44·9°	25	42·5	38·5	62·2	54·3	60·4	52·5
45° to 49·9°	22	47·2	42·6	63·0	55·0	60·5	54·8
50° to 54·9°	15	51·8	48·7	62·0	55 9	62 6	56·4
55° to 59·9°	16	57·4	52·2	65·0	58·3	65·7	59·2
60° to 64·9°	18	62·3	55 4	66·4	59·5	69·4	62·2
65° to 69 9°	17	66·8	57·9	68 7	61·6	71·4	63·6
70° to 74·9°	7	71·0	59·6	72·2	63·5	75·1	64·9
75° or more	6	77·4	64·5	76·0	65·8	78 2	67·1

In Table I are recorded the averages observed over 5° intervals. The data obtained for the smaller shop are particularly reliable, as the temperatures observed were extremely steady. For instance, in the 22 observations made when the outdoor temperature varied from 45° to 49·9°, the shop temperature varied only from 62·4° to 64·3° in 13 instances, and from 60·4° to 66·3° in 19 instances. Again, when the outdoor temperature varied from 40° to 44·9°, the shop temperature varied only from 60·4° to 66·3° in 21 out of the 25 occasions on which it was observed.

In Fig. 1 the average temperatures are plotted out, and it will be seen how closely the curve approaches the ideal. With outdoor temperatures varying from 34° to 55°, the mean shop temperature varied only from 61·5 to 63·0°; whilst at a mean outdoor temperature of 77·4° the shop temperature was only 76·0°, or 1·4° *lower*. The heating of the shop was effected by steam pipes fixed about 7½ ft. above floor level, and the ventilation was controlled by skylights.

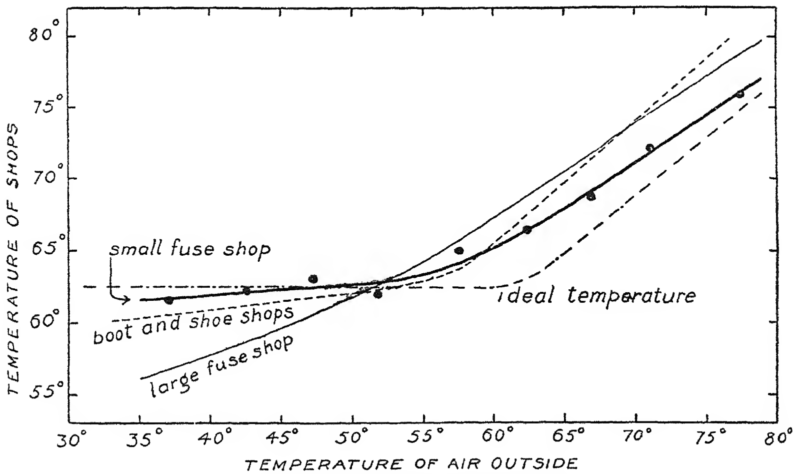


Fig. 1. Temperatures at engineering shops and at boot and shoe shops.

In the larger shop the temperature conditions were not so equable, or so well controlled. This was partly because of its great length, and partly because of the many kinds of machinery and processes in the shop, in contradistinction to the smaller shop, which contained practically nothing but lathes. The curve in Fig. 1 shows a considerable departure from the ideal, for the mean shop temperature varied from 55·4° to 62·6° when the outdoor temperature varied from 37·1° to 51·8°, and at the high outdoor temperature of 77·4° the shop temperature showed a temperature of 78·2°, or 0·8° in excess.

In the Boot and Shoe industry the investigators previously mentioned made temperature observations in 35 factories, and the 626 records obtained are classified in Table II. As would naturally be expected, there is a greater range of variation in the shop temperatures than that recorded at the smaller fuse factory shop, but it will be seen that at each outdoor temperature interval of 10° investigated a majority of the corresponding shop temperatures (which are recorded as percentages on their respective totals) varied only by 5° or less, except in one instance. The mean shop temperatures observed at outdoor temperatures of 30° to 60° were steadier than those observed at the big fuse shop, though less steady than those at the smaller shop, but at an outdoor temperature of 75° the shop temperature amounted to 78·4°, or 3·4° in excess. Hence the curve in Fig. 1 shows a fair approach to the ideal at outdoor temperatures of 60° or less, but a substantial departure from it at higher temperatures.

TABLE II.

Comparison of Outdoor and Indoor Temperatures in Boot and Shoe Factories.

Outdoor Temperature	Number of Observations.	Relative Frequency of occurrence of Factory Temperature.								Mean Factory Temperature.	
		Under 50°.	50° to 54·9°	55° to 59·9°.	60° to 64·9°.	65° to 69·9°.	70° to 74·9°.	75° to 79·9°.	80° or more.	Dry Bulb °	Wet Bulb. °
30° to 39·9°	74	3	12	**42**	28	14	1	0	0	59·7	51·8
40° to 49·9°	273	3	23	**53**	19	2	0	0	0	62·3	54·6
50° to 59·9°	147	0	0	18	**50**	31	0	1	0	62·4	56·3
60° to 69·9°	105	0	0	0	10	36	**50**	4	0	69·8	61·1
70° to 79·9°	27	0	0	0	0	0	8	**63**	29	78·4	65·7

TEMPERATURE OBSERVATIONS IN POTTERS' SHOPS.

Systematic investigations on temperature and cooling power were made during summer and winter in the potters' shops at eight pottery works, whilst less complete series were made at two other works. The thermometers were placed on the working benches at about 5 ft. above floor level, and two to seven sets of

observations were made on each occasion in each shop investigated. The actual number of observations depended on the size of the shop, but four was the most usual number. The hours of work in most potteries are 7.30 to 9, 9.30 to 1, and 2 to 5 30 p.m.; but temperature observations were made only from 9 to 1, and from 2 to 5. Every shop was investigated on one or more mornings, and one or more afternoons, and we made several sets of observations when the external temperature was (*a*) below 40°, (*b*) between 40° and 50°, (*c*) between 50° and 60°, and (*d*) between 60° and 70°, whilst in six out of the eight works we likewise made observations when the external temperature was over 70°. The winter observations were carried out in the months of November, December, and January, and the summer ones in July, August, and September.

Leaf and Draw-out Stove Shops.

Potters' shops provided with leaf and draw-out stoves proved to be somewhat hotter than those with other forms of stove, and in Fig. 2 are reproduced the mean temperatures observed in each of the five shops investigated The results obtained at each shop are indicated by a different sign, but for the sake of clearness only one curve is drawn, representing the mean temperature variation

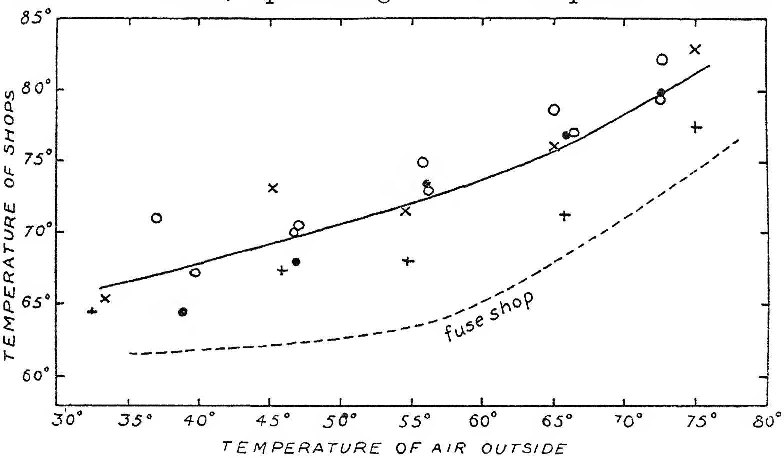


Fig 2. Temperatures in shops fitted with Leaf and with Draw-out stoves.

at the five shops. It will be seen from this curve that when the outside temperature was at 35° the shop temperature was at 66°, or about 5° warmer than at the smaller fuse shop, the curve of which is inserted for the purposes of comparison. At an outside temperature of 55° the shop temperature averaged 72°, or about 9° higher than at the fuse shop; whilst at an outside temperature of 75° it averaged 82°, or 7° more than at the fuse shop. Hence the potters' shops were consistently hotter than the fuse shop at all seasons of the year, the average excess of temperature being about 7°. As is pointed out in the subsequent report, the high temperatures observed were partly due to faults inherent in these particular types of stoves, for the more modern type of draw-out stove

appears to be no better than the older form of leaf-stove with laterally moving leaves. Thus the temperatures indicated in Fig. 2 by crosses relate to shops fitted with very large draw-out stoves (*cf.* Plate II), and these values are in most cases nearly as high as the others, which relate to shops with lateral leaf stoves (*cf.* Plate III). Moreover, they do not indicate the full amount of heat passing from the stoves into the shops, as there were several chamber stoves present in addition, and judging by the temperature of the air in their neighbourhood these stoves emitted less heat than the draw-out stoves.

The high shop temperatures are also due in some degree to the inclination of the potters themselves, and of this we obtained a numerical proof. Whenever temperature observations were made in a shop, we noted the number of windows and skylights which were (*a*) shut completely; (*b*) half open; (*c*) wide open. The great majority of the windows were of the usual hopper type, and were so arranged that they could be fixed at the half-open or the wide-open position; but in a few works they could only be half opened, whilst some of the skylights—which represented only a small fraction of the total lighting area—were fixed. Hence the data recorded on the right side of Table III refer only to windows and skylights which could be opened or not as the potters desired.

TABLE III.

Mean Atmospheric Conditions in Potters' Shops.

Type of Stove in shops.	Number of shops and works investigated.	Average Number of sets of observations in each shop.	Temperature of air outside		Temperature of air in shop		Velocity of air current.		Percentage number of windows			Percentage window space open.
			Dry bulb	Wet bulb.	Dry bulb	Wet bulb.	Outside	In shop	Shut	Half open	Open	
			°	°	°	°	ft per min.	ft per min				
Leaf and Draw-out	5 shops at 2 works	3 8	36 3	34 9	66·5	57·0	158	15	88	8	4	8
	,, ,,	4 8	46·3	43·2	69 8	60·0	235	16	78	21	1	11
	,, ,,	4 8	55 4	51·0	72 2	62 1	254	20	48	42	10	31
	,, ,,	5 6	65 6	57·1	76 0	65 0	199	21	19	61	20	51
	,, ,,	2 0	73 5	61·5	80 4	67·3	158	21	10	57	33	62
Dobbin .	7 shops at 4 works	3 3	36 2	34 6	66 5	58 4	185	22	73	27	0	13
	8 ,, 5 ,,	4 4	45·4	42·0	68 6	60 5	199	21	59	30	11	26
	,, ,,	5·1	55 8	51·1	70 0	62 1	210	26	40	35	25	42
	,, ,,	8·1	64 2	57 2	73·7	64 9	162	28	18	36	46	64
	,, ,,	3 1	74 0	63·2	81 2	70 2	204	22	14	25	61	74
Chamber .. (shops too hot)	6 shops at 3 works	3 2	37 0	35·5	67·1	58 2	179	17	77	15	8	15
	,, ,,	3 5	44·3	41 4	66 9	59 0	206	18	62	32	6	22
	,, ,,	5·2	54·8	50 5	70 2	62 0	238	19	31	50	19	44
	,, ,,	7 3	64 2	57·9	74·2	65 4	221	22	15	48	37	61
	,, ,,	3 2	74·8	63 9	79 5	68·5	255	33	10	43	47	68
Chamber . (shops fairly correct)	5 shops at 4 works	3·2	35·7	34·3	59 6	52 5	164	20	89	11	0	5
	7 ,, 5 ,,	6 0	44·9	42 4	63 7	57 5	204	18	80	19	1	11
	6 ,, 5 ,,	4 0	56 7	52 4	66·4	59 5	212	21	42	50	8	33
	7 ,, 5 ,,	7 3	64 0	57·9	71 4	63 4	202	25	27	55	18	45
	,, ,,	3 0	75 1	64·4	78·6	68 5	179	20	23	52	25	51
Chamber .. (shops too cold in winter)	1 shop at 1 works	2 0	36 5	36 3	56 0	52 6	105	19	0	100	0	(50)
	3 ,, 2 ,,	4 7	43 0	41·3	56·9	52 0	206	21	58	42	0	21
	,, ,,	4 0	56 4	51·2	61 7	56·3	217	19	13	75	12	49
	,, ,,	8 3	64·1	58 3	68 1	64 8	165	26	0	70	30	65
	,, ,,	2 0	73 9	61 7	75·2	66 1	205	30	0	70	30	65
Cabinet ..	3 shops at 2 works	4 3	37·7	36 2	55 8	50·9	265	18	96	3	1	2
	,, ,,	7·3	43·9	41 3	62·9	55 9	216	16	89	11	0	5
	,, ,,	3 3	56 6	52·7	68 3	60·6	254	18	53	36	11	29
	,, ,,	7 0	64·0	58 9	72 2	64·1	153	24	40	38	22	41
	,, ,,	2 7	73 0	64 7	75 4	66 3	133	47	21	41	38	58

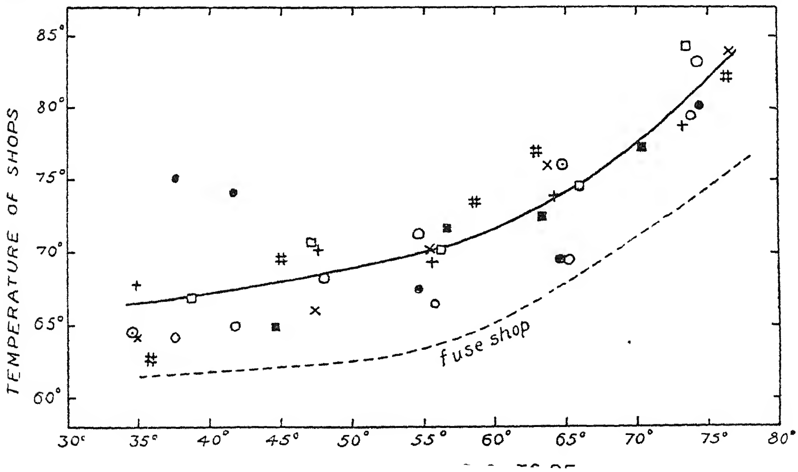
It will be seen that in the leaf and draw-out stove shops 88 per cent. of the windows were shut completely, when, in winter time, the shop temperature averaged 66·5° and the outdoor temperature averaged 36·3°. Of the remaining windows, 8 per cent. were half open and 4 per cent were open. Roughly speaking, one may say that a window, when wide open, allows about twice as much ventilation as when it is half open, so that the total open window space of which the potters availed themselves came to 8/2+4=8 per cent. of the maximum possible. It will be seen in the Table that when the outdoor temperature was at 46·3°, the shop temperature averaged 69·8°, but even then the potters opened very few more of their windows, and altogether they made use of only 11 per cent. of their available window space. Evidently, therefore, they *liked* a shop temperature of about 70°. This was about the limit of their preference, for we see that at shop temperatures of 72°, 76°, and 80° they opened up 31, 51, and 62 per cent. respectively of their window space. However, they did not appear to feel even a temperature of 80·4° very severely, for if they did, why should they still keep 10 per cent. of their windows shut completely, and 57 per cent. of them half shut? It should be pointed out that windows in the half open position caused no direct draught on the potters, though they often did when in the fully open position.

We occasionally noted down the opinions of the potters themselves, at the time shop temperatures were being determined, and the data tabulated suggest that a temperature slightly under 70° suits them best, but insufficient opinions were collected to be reliable

Temperature recorded.	*Opinions of potters.*
84·3, 78·9, 78·8, 75·0 ..	"Too hot."
73·8, 72·6, 70·3, 69·9 ..	"Rather too warm."
72·0, 69·5, 69·2, 67·0, 65·9	"Just right," "fine," "all right"
61·0, 57·7	"Rather cool."

Dobbin Stove Shops.

Observations were made in eight shops, situated in five different pottery works, where the drying stoves were of the dobbin type.



The mean results are recorded in Table III, and in Fig. 3. It will be seen that in no single instance, whatever the outdoor temperature, was the shop temperature as low as that observed in the fuse shop. The mean curve indicates that the temperature was always about 6° higher than that of the fuse shop, both in summer and winter. At one shop the windows were kept so shut up in the winter months that the shop temperature was 5° to 7° higher than in ordinary summer weather, when most of them were opened, but taking all the results together, the potters were better at opening windows than those working in leaf and draw-out stove shops. Thus at a shop temperature of 68·6° they had 26 per cent. of their available window space open, and at one of 81·2° they had 74 per cent. of it open.

Chamber Stove Shops.

Observations were made in 16 chamber stove shops, situated in six different works. The temperatures differed considerably, and for convenience of description they have been arbitrarily divided into three groups. The first group relates to the shops which, in comparison with our fuse shop standard, were always too hot. As can be seen from the upper set of values in Fig. 4, the temperature in individual shops was always 3° or more above

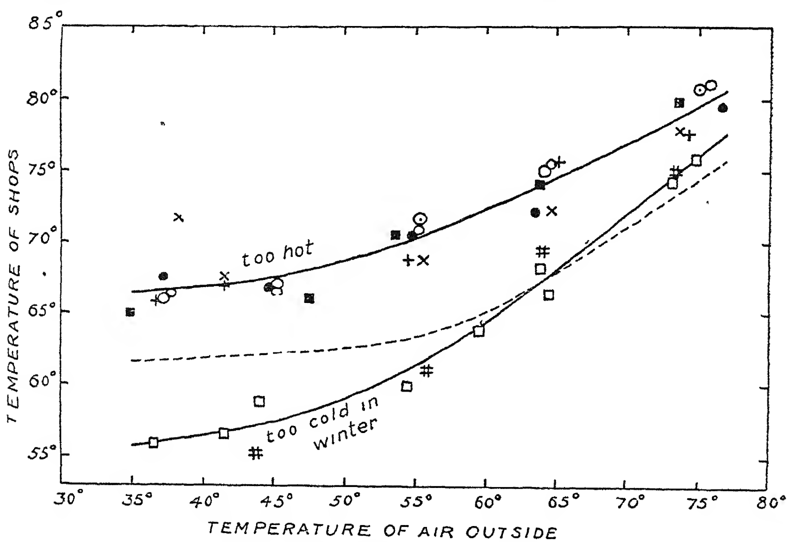


Fig. 4. Temperatures in over-heated and under-heated shops fitted with Chamber stoves.

that observed in the fuse shop, both in summer and winter, whilst the mean curve is almost the same as that obtained with dobbin stove shops. The lower curve drawn in Fig. 4 relates to three shops where the temperature was nearly correct in the summer, but was several degrees too low in the winter. Thus at an outdoor temperature of 43° it averaged only 57°, or about 5° below the theoretical.

At the remaining six shops the temperatures corresponded fairly well with the theoretical, as can be judged from Fig. 5, though even in them the summer temperatures were about 4° too high. From the data recorded in Table III it will be seen that the potters in these reasonably heated shops kept 11 per cent. of their window space open when the shop temperature averaged 63·7°, but they kept 33 per cent. open when it rose to 66·4°, and 45 per cent. when it rose to 71·4°. In other words, they appeared to prefer a temperature of 65° or less, and not one of

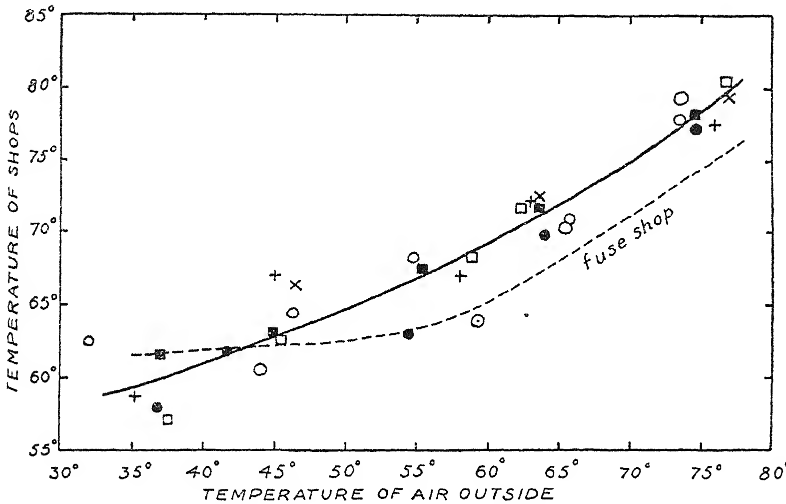


Fig. 5. Temperatures in reasonably heated shops fitted with Chamber stoves.

70° like the leaf and draw-out stove shop potters. The potters in the group of cool-chamber stove shops seem to have been fresh air devotees, for they kept 21 per cent. of their windows open when the shop temperature was at 57°, 49 per cent. of them when it was at 62°, and 65 per cent. when it was at 68°. However, they were quite exceptional in this respect, for the potters in the seven overheated chamber stove shops resembled those in the dobbin stove and leaf stove shops, in that they opened only 15 per cent. of their windows when the shop temperature was at 67°.

Cabinet Stove Shops

Observations were made only in three shops provided with cabinet stoves, and two of the shops were at the same works. It will be seen from Fig. 6 that the mean curve conforms fairly well with the theoretical, except on cold winter days, when it was much too low. When the outdoor temperature was at 37·7°, the shop temperature averaged only 55·8°, in spite of the fact that the potters kept 96 per cent. of their windows completely shut. Even when the outdoor temperature was at 44° the shop temperature was only at 63°, in spite of all but five per cent. of the window space being closed. It was only when the shop temperature rose to 68° that the potters opened a

fair area (29 per cent.) of the available window space, so it is evident that they wanted to keep up their shop temperature to about 67°, but were unable to do so. As is indicated in the subsequent report, these low shop temperatures in winter time are due to the cabinet stoves retaining most of the heat derived from the steam pipes within them. This is a desirable quality in all potters' stoves, but it implies that an adequate shop temperature in winter time can be attained only by the installation of an independent system of heating in the shops.

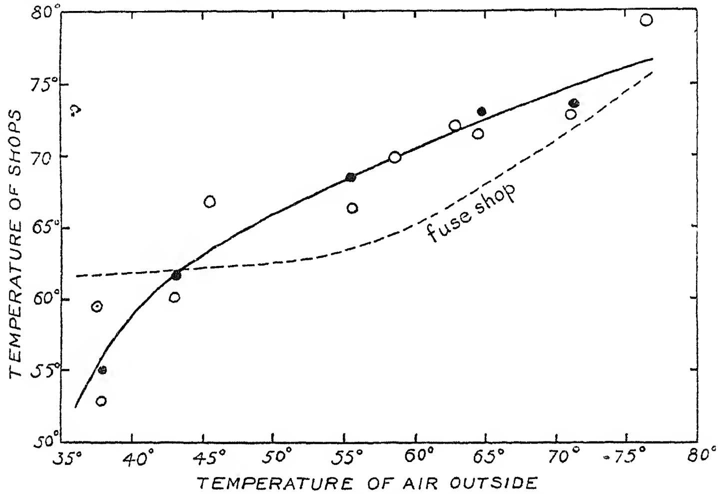


Fig. 6. Temperatures in shops fitted with Cabinet stoves.

Grouping together all the 32 shops investigated, we have seen that 19 of them were considerably too hot at all times of the year. The remaining 13 shops conformed fairly well to the theoretical during the summer, though they were rather too warm, but six of them were distinctly too cool for comfort in winter time.

All the temperatures recorded in Table III and in Figs. 2 to 6 are, with one exception, averages of three or more sets of observations, and it by no means follows that an *average* temperature of, *e.g.*, 65°, represents comfortable conditions in the shops, for it may comprise the mean of widely divergent temperatures, *e.g.*, 55° and 75°, on different days. As a matter of fact the temperatures met with in the shops, whether high or low, were in almost all instances fairly consistent. Nearly the same amount of earthenware or china ware was produced in each shop day after day, hence the stoves in the shops required the same amount of heat for drying purposes. This heat was obtained by turning on more, or less, of steam to the steam pipes in the stoves, so as to obtain about the same stove temperature whatever the season of the year. Hence it follows that the warmer the outdoor temperature the less the amount of heat passing from the stoves to the shops.

Excess of Indoor Temperatures over Outdoor Temperatures.

From the data already quoted, it is evident that the mere statement of the shop temperature, without any information as to the temperature outside, does not afford sufficient evidence to enable us to estimate the suitability of the artificial heating of the shop. The heating raises the shop temperature a certain number of degrees above outside temperature, and it is this number which gives the requisite information. Accordingly, the temperature observations made in all the shops of the ten works visited have been recorded in Table IV according to their excess above the corresponding outdoor temperatures. We see that 97 sets of observations were made when the outdoor temperature was less than 40°, and of this number three per cent. showed a 10° to 15° excess of over the outdoor temperature; eleven per cent. showed a 15° to 20° excess, ten per cent. a 20° to 25° excess,

TABLE IV.

Excess of Indoor Temperatures over Outdoor Temperatures.

Excess of Indoor Temperature over Outdoor Temperature	Relative Frequency of Occurrence of Excess when Outdoor Temperature was				
	Less than 40°	40° to 49·9°	50° to 59·9°	60° to 69 9°	70° or more.
Below 0° F	—	—	—	1	2
0° to 4 9°	—	—	5	16	58
5° to 9 9°	—	1	20	45	33
10° to 14 9°	3	9	36	36	7
15° to 19 9°	11	34	30	2	—
20° to 24 9°	10	42	9	—	—
25° to 29 9°	39	10	—	—	—
30° to 34 9°	29	4	—	—	—
35° to 39 9°	8	—	—	—	—
Mid Indoor Temperature	35° + 28·2°= 63·2°	45° + 20 6°= 65 6°	55° + 13·4°= 68·4°	65° + 8·6°= 73·6°	75° + 4·1°= 79·1°
Number of sets of Observations	97	181	149	238	89

and so on. The *median* or middle value of the whole series corresponded to an excess of 28·2°, and if the mean outdoor temperature be taken as 35°, it follows that the median indoor temperature amounted to 35+28·2°=63·2°. This is approximately the ideal temperature, but it must be remembered that it is a mean of widely divergent temperatures, the extremes of which were, in actual fact, 48·1° and 77·1°. Still, 68 per cent. of all the values show an excess of 25° to 34·9°, or correspond to an indoor temperature of 60° to 69·9°.

The median value for the temperature excess when the outdoor temperature ranged from 40° to 49·9° was 20·6°, so the actual shop temperature was 45°+20·6=65·6°. This is likewise a reasonable temperature, but it is the mean of very divergent values. With higher outdoor temperatures the divergence got less and less, till at temperatures of 70° or more the shop

temperature was found to show an excess of 0° to 4·9° in 58 per cent. of all the observations made. In fact, it was only in seven per cent. of the observations that the shop temperature exceeded the outdoor temperature by more than 10°. In two per cent. of the observations the shop temperature was *less* than that observed outside.

The Humidity of the Air.

The air in potters' shops contains a considerable amount of moisture, partly because of the presence of the large masses of moist clay, but more especially because of the back draught from the stoves, which carries with it much of the moisture from the drying ware. It might be taken that this implies a high relative humidity, and in order to test this question, wet bulb readings were always made at the same time as those of the dry bulb, both indoors and out of doors. The mean wet bulb temperatures observed are recorded in Table III. The percentage saturation of the air with moisture was calculated, for each pair of wet and dry bulb temperatures, from Glaisher's Hygrometrical Tables. The dry bulb temperature of the potters' shops almost always fell within the limits of 60° and 80°, so all the observed humidities have been split up into two groups, according as they relate to a dry bulb temperature of 60° to 69·9°, or to one of 70° to 79·9°.

All the data in Table V relate to dry bulb temperatures of 60° to 69·9°, and it will be seen that in 34 per cent. of the 268 sets of observations made in potters' shops a humidity corresponding to 50 to 59 per cent. saturation was observed, whilst in 48 per cent. of them it ranged from 60 to 69 per cent. The average humidity came to 62 per cent, and this is distinctly smaller than the humidity of the outdoor air, which averaged 67 per cent saturation. It is to be remembered that these outdoor

Table V.

Relative Frequency of Various Degrees of Humidity at 60°—70°.

Percentage Saturation	Potters' Shops		Fuse Shops.		Boot and Shoe Shops
	Air Inside	Air Outside	Air Inside.	Air Outside	
Under 50	2	6	3	12	5
50 to 59	34	20	35	46	44
60 to 69	48	32	44	23	42
70 to 79	16	30	17	14	9
80 to 89	—	9	1	5	—
90 or more	—	3	—	—	—
Mean Saturation	62	67	62	60	60
Number of Observations	268	94	204	43	403

observations were made only in the summer months—*i.e.*, when the temperature was at 60°–70°—whilst many of the potters' shop observations were made in winter. Still, the fact remains that the air in the shops showed a lower relative humidity than the outside air at similar dry bulb temperatures. For purposes of comparison, the corresponding fuse shop observations are recorded, and it will be seen that whilst the humidity inside the shops was the same as in the potters' shops, the humidity of the outside air was smaller. The 403 observations made on the air in the boot and shoe shops showed a slightly lower humidity than that observed in the potters' shops and the fuse shops The outdoor observations were so few in number that they are not worth quoting, but probably the humidity was something between the 60 per cent. and 67 per cent. values recorded in the potters' shop and fuse shop localities. To substantiate this statement, we averaged some of the numerous hygrometrical observations which are regularly recorded at the Radcliffe Observatory, Oxford. Taking all the hourly readings between 8 a.m. and 4 p.m. (corresponding to 9 and 5 p.m. during our present system of summer time) in the months of July, August and September, we found that in the years 1900 to 1905 the average humidity came to 65 per cent. Again, outdoor observations made at the Godlee University, Manchester, in 1914 to 1915, point to a similar figure. The data obtained relate to the whole 24 hours of each day, and as the humidity over this period is considerably greater than that observed during working hours (9 to 5), an appropriate correction was made, based on the Oxford observations This gave a mean humidity of 63 per cent. at Manchester on such days as the average temperature was 60° to 70°. Another set of hygrometrical observations made at Swansea in 1911 to 1918 gave, after due correction, an average humidity of 65 per cent. during working hours (9 to 5), on such days as the temperature averaged 60° to 70°. Hence the various sets of outdoor observations obtained in different localities gave the fairly consistent mean humidities of 60, 63, 65, 65 and 67 per cent.

At outdoor temperatures of 70° to 80° the humidity of the air is very much less than at 60° to 70°, for such temperatures are usually experienced only for a few hours in the afternoon, owing to the sun's rays rapidly warming the relatively cool and humid morning air. Thus we find, from the records in Table VI, that the air outside the potters' shops had an average humidity of only 52 per cent., whilst observations at Oxford, made between 8 and 4 p.m. in July, August and September, 1887, gave an average humidity of 51 per cent. Only 16 observations were made outside the fuse shops, and they gave an average humidity of 48 per cent. In comparison with these figures, the humidity of the air in the potters' shops amounted to 58 per cent., that in fuse shops to 59 per cent., and that in boot and shoe shops, to 53 per cent. Hence it follows that at temperatures of 70° to

TABLE VI.

Relative Frequency of Various Degrees of Humidity at 70°—80°

Percentage Saturation	Potters' Shops.		Fuse Shops	Boot and Shoe Shops	Outside Air at Oxford
	Air Inside	Air Outside			
Under 40	—	3	—	—	6
40 to 49	11	42	2	40	42
50 to 59	45	37	54	35	37
60 to 69	39	13	39	19	14
70 to 79	5	5	5	1	1
Mean Saturation	58	52	59	53	51
Number of Observations	319	38	59	95	163

80° the air in potters' shops is distinctly more humid than outside air, but it is probably not more so—or very little more so—than that observed in the shops of other industries. In any case the relative humidity is not at all excessive, for we see that only in five per cent. of all the observations was the air more than 70 per cent saturated, and in no instance did it show a saturation amounting to 80 per cent.

Putting together the observations at 70°–80° and those at 60°–70°, we may conclude that the humidity of the air in potters' shops is approximately the same as that observed in outside air at corresponding temperatures. It might be thought that this statement contradicts the undoubted fact that the air contains large quantities of moisture derived from the moist clay and the drying ware, but it is not so. Owing to the high temperature to which the air in the shops is heated, it can carry very much more moisture than the outside air without any increase of saturation. For instance, if air half saturated with moisture at 50° is heated to 70°, it can carry 97 per cent. more moisture and still remain half saturated. If heated to 80°, it can carry 170 per cent. more moisture, again keeping at half saturation. It follows that there is no good reason why potters' shops should be subject to the pottery regulation requiring the installation of wet bulb thermometers, more than the shops of other industries. It would, however, in some respects be better to instal such thermometers in the workshops of all industries, rather than dry bulb thermometers, as the wet bulb temperature is a much better index of comfort than the dry bulb temperature (*cf.* Vernon, 1922). Best of all would it be to instal both wet and dry bulb thermometers, so that the humidity of the air could be readily ascertained, and remedial measures be taken on exceptionally hot and humid days.

The present system of installing wet bulb thermometers in potters' shops is subject to one serious disability. In our experience, a very large proportion of the thermometers are neglected, and allowed to go dry. Hence they are apt to yield very misleading information, unless the precaution is taken of seeing that they are in good working order.

The Velocity of the Air Currents.

As already mentioned, the cooling power of the air in potters' shops was determined by means of the kata thermometer From the cooling power values the air velocity was calculated by means of the following formulæ, which have recently been obtained by Hill, Vernon and Hargood-Ash (1922), as the result of consistent observations by two different methods :—

(*a*) For air velocities less than 1 metre per sec. (198 ft. per min.) :

$$H/\theta = 0 \cdot 20 + 0 \cdot 40 \sqrt{V}$$

(*b*) For air velocities greater than 1 metre per sec. :

$$H/\theta = 0 \cdot 13 + 0 \cdot 47 \sqrt{V}$$

Where H is the cooling power, θ is the difference between 36·5° and the air temperature in degrees centigrade, and V is the air velocity in metres per sec

For the convenience of other investigators, an abridged Table of equivalents between $H/0$ and air velocities (in feet per min.) is given at the end of this report (Table XI).

The mean air velocities observed in shops with various types of potters' stove are recorded in Table III, but they are re-grouped in Table VII, so as to bring out the average relationship of air currents to temperature and to type of stove From the right half of the Table we see that with rise of outdoor temperature there was a gradual increase of air currents, till at temperatures of 70° and upwards the velocity amounted to 29 ft. per min., as against the value of 18 ft. which was observed at temperatures below 50°. This increment is not due to variations in the velocity

Table VII.

Velocity of Air Currents in relation to Air Currents and Type of Stove.

Type of Stove in Shops	Velocity of Air Currents Outside at						Velocity of Air Currents in Shops with Outside Temperature of					
	37°	45°	56°	64°	74°	Mean.	37°	45°	56°	64°	74°	Mean
Leaf and Draw-out	158	235	254	199	158	201	15	16	20	21	21	19
Dobbin ..	185	199	210	162	204	192	22	21	26	28	22	24
Chamber ..	167	205	223	202	211	202	18	19	20	24	27	22
Cabinet ..	265	216	254	153	133	204	18	16	18	24	47	25
Mean ..	194	214	235	179	176	200	18	18	21	24	29	22

of the outdoor air currents, for they were considerably less at 60°–80° than at 40°–60°. It was effected by the opening of doors and windows, for the average amount of window space kept open when the outdoor temperature was at 37°, 45°, 56°, 64° and 74° came to 9, 14, 35, 53 and 64 per cent. respectively. It will probably be thought that the window opening would have effected a much greater increase of air currents than that actually observed. The reason why it did not do so is presumably to be attributed to the differences of temperature inside and outside the shops. The stoves, which are generally situated in the middle of each shop, emit considerable back draughts of hot air, and this air passes towards the roof and windows of the shop, where it is cooled. It sinks to the floor, and thence is drawn back into the stoves. Hence there is a continuous circular movement of the air in the shop, and the rapidity of this movement tends to be greater and greater in proportion to the difference between the temperature of the back draught and that of the windows and roof Now the temperature of these structures varies with that of the outside air, whilst that of the back draught air is nearly constant at all times of the year (*cf.* subsequent report). Consequently the circular movement of the air in the shops tends to get less and less the hotter the air outside. We saw that in actual fact the air currents, whether circular or horizontal, got more rapid owing to the opening of windows, but much of the increased rapidity so induced must have been neutralised in the manner described.

In order to obtain direct numerical proof of the effect of opening windows on the velocity of the air currents in a shop, an experiment was made in a square shop, well supplied with windows on all four sides. Readings were first taken on a cold day when 19 out of the 20 hopper windows were shut, and the air velocity averaged 17 ft. per min. All but two of the windows were then opened to half their full extent, and the air velocity was found to have increased to 32 ft. per min. The temperature of the shop fell, in the course of half an hour, from 54·9° down to 53·3°, and the workers complained of draughts.

Another experiment was made in a long and narrow shop during summer weather. When the hopper windows were in the half-open position, the air velocity averaged 24 ft. per min., and the temperature, 77·5°. After opening 15 out of the 17 windows to their full extent, the air velocity increased to 28 ft. per min., and the temperature of the shop fell, in half an hour, to 75·1°.

It will be seen from Table VII that the air velocity was not much influenced by the type of stove in the shops. The air in leaf and draw-out stove shops, which were the hottest of all, had the lowest velocity, viz., 19 ft. per min. whilst that in cabinet stove shops, which were the coolest, had the greatest velocity, viz., 25 ft

per min. Chamber stoves, however, which were cooler than dobbin stoves, had a slightly lower velocity.

In order to compare the air velocities in potters' shops with those in boot and shoe shops, the data have been tabulated on corresponding lines in Table VIII. The boot and shoe data for single-storey and multi-storey buildings have been averaged, and it will be seen that in " winter time " (*i.e.*, when the outdoor temperature was under 50°) an air velocity of 24 ft. or less was observed in 13 per cent. of all cases, whilst in " summer time " (*i.e.*, when the outdoor temperature was 50° or more) this velocity was observed in 18 per cent. of all cases. In potters' shops, on the other hand, 82 and 62 per cent. respectively of the observations showed this low velocity. The median or middle velocity came to 17 and 21 ft. respectively for winter and summer observations in potters' shops, whilst it came to 35 and 37 ft. for boot and shoe shops, or nearly double as much. Evidently, therefore, the potters' shops were greatly under-ventilated, if boot and shoe shops be taken as a type of suitably ventilated shops in an industry requiring moderately active work on the part of the operatives.

TABLE VIII.

Air Velocities in Potters' Shops and in Boot and Shoe Shops.

Air Velocity in Feet per Minute	Potters' Shops		Boot and Shoe Shops	
	Winter	Summer.	Winter	Summer
Under 10	3	4		
10 to 14	28	13		
15 to 19	32 } 82	24 } 62	} 13	} 18
20 to 24	19	21		
25 to 30	13	16	21	15
31 to 35	3	7	17	13
36 to 40	1	6	14	14
41 to 51	1	3	19	20
52 to 74	—	5	9	10
75 or more	—	1	7	10
Total Observations	289	463	373	273

In humid cotton-weaving sheds Wyatt observed velocities somewhat greater than those in potters' shops, but much smaller than those in boot and shoe shops. Seven sheds were tested, and the mean winter observations gave velocities of 21 to 31 ft. (mean, 25·6 ft.), whilst the summer observations gave velocities of 18 to 40 ft. (mean, 26·0 ft.). Owing to the fact that the shop temperature was high (74·4° in summer and 70·7° in winter), and the air was very humid (72 per cent. saturated in summer and 74 per cent. in winter), the atmospheric conditions were extremely trying. They should have been compensated for, so far as possible, by much more rapid air velocities than those actually found.

The cooling power of the air depends chiefly on the difference between the temperature of the human body and that of the surrounding air, and on the velocity of movement of this air. These two factors, combined together, can be estimated in terms of "cooling power" by means of the dry kata thermometer. Dr. Hill and other investigators have laid great stress on the importance of estimating and comparing the cooling powers of the air in workshops and rooms, but it is always to be remembered that the powers so compared are dependent on two variables, and that they can teach us comparatively little unless we know the two components on which they depend. For instance, a shop with absolutely still air at 50° has the same cooling power as a shop at 62° with an air current of 32 ft. per min, and as one at 80° with an air current of 320 ft. per min., yet neither the first nor the last of these three sets of atmospheric conditions would be nearly so pleasant to work in as the intermediate one.

The cooling power of the air in potters' shops must evidently compare badly with that in boot and shoe shops, for we have seen that it has both a higher temperature and a lower velocity. In Table IX the data have been classified under the headings

TABLE IX.

Cooling Power of Air in Potters' Shops and in Boot and Shoe Shops

Dry Kata Thermometer Cooling Power.	Potters' Shops		Boot and Shoe Shops	
	Winter	Summer	Winter	Summer
Below 3	0	6	0	0
3 to 3·9	3	23	0	8
4 to 4·9	18	**34**	1	10
5 to 5·9 . ..	**40**	26	4	19
6 to 6·9 . . .	24	8	28	**28**
7 to 7·9	12	2	**35**	20
8 to 8·9	3	1	18	9
9 or more . ..	0	0	14	6
Total Observations	289	463	377	276

of "summer" and "winter" observations, as before, and the boot and shoe data (the means of the multi-storey and the single-storey figures) are given in parallel columns. It will be seen that the cooling power of the air in the potters' shops fell far behind that of the boot and shoe shops, the median values of the former being 5·6 and 4·5 for winter and summer observations respectively, and of the latter, 7·4 and 6 4.

BODY MOVEMENTS OF POTTERS.

The cooling power of the air is dependent on another factor, which has not hitherto been investigated. This is the movements of the workers themselves. Supposing that a potter, who is working in an air current at a velocity of 20 ft. per min., has to

move his body at an average rate of 30 ft. per min in order to carry out his industrial operation, it follows that the effective air velocity, so far as he is concerned, is something between 10 ft per min. (when he is moving more or less in the direction of the air current), and 50 ft. per min (when he is moving against it), instead of 20 ft. In that his movements are made at an irregular rate, and the air current is probably variable in direction and strength, it is impossible to fix the effective velocity closely, but perhaps it is, in most potters, about midway between the extreme possible limits.

The cooling effect of moving air operates in chief part on the face and head, for the rest of the body, with the exception of the fore-arms, is normally covered by clothes. Hence almost all the observations to be described relate only to the *head movements* of the workers, rather than the body movements. Our method of procedure was a rough and ready one, but it gave consistent results, and a more accurate method would be difficult to carry out. Supposing the movements of a man engaged in making plates on a jolly were under investigation, a few rough measurements of the range of his chief movements were first made with a 2 ft. rule, which was held in one hand. In the other hand a stop watch was carried, and on starting the watch the number of feet through which the potter moved his head was estimated by eye as they occurred, with an occasional glance at the 2 ft. rule to serve as a standard. After about two minutes the watch was stopped, and the number of feet moved in a minute was calculated. We each made two or more sets of observations on each worker, and took a mean. A sample series, made upon plate makers, will show the kind of consistency attained. The observations in italics were made by H. M. V., and those in plain figures, by T. B.

Head Movements of Plate Makers.

Male No. 1..	*28*, *24*, 30, 29	=28	30 ft. per min.
,, No. 2..	*32*, *34*, 26, 25, 24	=28	
,, No. 3..	*28*, *27*, 30, 29	=29	
Female No. 1	32, 37, 32	=34	

It will be seen that the men showed almost exactly the same extent of head movement, whilst the woman moved rather more than they. The individual workers are usually fairly consistent, but not always. For instance, four saucer makers in one shop showed mean head movements of 40, 43, 43 and 45 ft. respectively, whilst a fifth moved only 29 ft per min.

In Table X are recorded the majority of our observations, which were made on various classes of workers in six pottery works. All the values recorded are means of two or more observations. Some of them relate to single workers, but the larger number are averages for two or more workers. It will be seen that in most of the so-called primary operations, not only on plate, saucer and cup making by means of jollies, but on other

Table X.

Head Movements of Various Workers.

Works	Primary Operation	Movements in feet per min: H M V	T B	Mean		Related Operation.	Movements in feet per min: H.M.V	T B	Mean
D	Man making plates on jolly	26	30	28		Girl mould runner	45	47	46
D.	Do do.	33	25	29	30	Girl helper preparing body . . .	22	20	21
D	Do do	28	29	29		Boy mould runner .	74	67	71
D	Woman do	—	34	34		Girl helper preparing body	27	19	23
						Girl mould runner .	58	34	45
K.	Men making saucers on jollies	32	25	29		Boy mould runners .	63	110	87
K.	Do do.	37	43	40	35	Boy helpers preparing body .	30	20	25
H.	Do. do.	31	44	37		Boy mould runners . .	89	70	80
H.	Girls making cups on jollies.	15	—	15		Boy and girl mould runners . . .	76	82	79
H	Do. do	20	26	23	19	Girl mould runners .	55	—	55
F	Man making basins on jolly	30	—	30		Do. do	80	95	87
E	Men throwers . .	—	12	12		Do. do.	74	—	74
E	Men turning jugs .	—	12	12					
F.	Men turning bowls .	32	36	34					
J	Women fettling fancy articles	11	13	12					
K	Women fettling plates	19	—	19	19				
D	Do do	27	18	22					
F.	Women fettling toilet articles	25	23	24					
J	Women casting fancy articles. .	20	30	25	24				
J.	Do do	22	24	23					

operations such as fettling and casting, the head movements amounted to 20 or 30 ft. per min. In the related operations, which concern the boys and girls who assisted the potters, the helpers who prepared the clay or china body showed 20 to 25 ft. of head movement. The mould-runners, on the other hand, showed much more movement, and attained an average figure of 70 ft. per min. The extent of their movements necessarily varies greatly from time to time, for at one moment the runner may have to carry the moulds to the shelves of a stove close at hand, and soon after, may have to walk to a stove 12 ft. off, and then deposit the moulds at the far end.

We saw that the median air velocity in potters' shops was about 19 ft. per min., whilst that in boot and shoe shops was 36 ft. We have no information as to the head movements of boot and shoe operatives, but if they are inconsiderable, it follows that many of the potters may, after all, experience as great an effective air velocity as they Mould runners, in fact, probably experience a considerably greater velocity. It is curious to think that, within certain limits, the more quickly an operative moves about in the course of his work, the less would he notice whether a shop was badly ventilated or well ventilated. The acme of such a contrast is met with in the mule spinners at cotton mills, who have to carry out their work in very hot and slightly ventilated shops, but as they are constantly walking backwards and forwards at the rate of about two miles per hour in order to attend to their mules, they create a velocity of air movement against their bodies amounting to 176 ft. per min.

It is true that the more quickly a man is moving, the more heat his body produces, and the greater the velocity of air movement necessary to keep down his body temperature; but considerable air velocities in shops are very difficult to produce, and as a rule the quickly moving worker does not expect them. He gets rid of his extra body heat by increased perspiration.

All the observations recorded in Table X were made in the winter, but many of them were repeated in the summer. They yielded similar values, though on an average the movements came to 2 ft. per min less. Data relating to mould runners are not included in this estimate, owing to their irregularity.

Arguing from the information acquired by motion study in other industries, it is probable that the quickest and most skilful potters would, as a rule, make smaller body movements than the slower and less skilled workers. An attempt was made to obtain numerical evidence on the subject by investigating the output and body movements of eight men, all of whom were engaged in making china saucers on jollies. Their output was ascertained for 12 weeks, and the head movements of each man were measured on three or four occasions. The two men showing the smallest head movements (27·8 ft per min.) had the largest output, viz., 107 per week. The three men with an intermediate degree of head movements (31·5 ft. per min.) had an average output of 98 per week, whilst the three men showing the greatest head movements (37·3 ft. per min) had an average output of 97 per week. Hence the observations, so far as they go, show a distinct relationship between output and economy of head movements. However, they require repetition on a much larger scale before they can be accepted as conclusive.

General Conclusions.

There can be no doubt that potters' shops in general are kept at a considerably higher temperature than that considered suitable in other industries, such as those of engineering and boot and shoe manufacture, which require work of a corresponding degree of activity on the part of the operatives. As is shown in the subsequent report, this excess of heat is dependent largely on the faulty construction of the potters' drying stoves. At the same time it must be admitted that the potters themselves are to some extent responsible for the high temperatures. They are careless about keeping their stove doors shut, as well as being backward in opening the shop windows The reason is that the potters have, for the most part, been engaged in the industry since the age of 14, and they have got so acclimatised to the heat that they feel uncomfortable without it. It may be maintained that high temperature and small degree of air movement do no harm, and should therefore be permitted. It is true that the evidence of the harmfulness of such conditions is indefinite and inexact, but we think it is quite sufficient to establish its claims. Firstly, it is evident that on bitterly cold days workers who spend all their working hours in overheated shops must be more liable

to catch chills, when they go into the open air, than those who have been working in reasonably heated shops. Lack of ventilation, whether in private houses or workshops, is well known to cause increased liability to coughs and colds.

Hill (1919) points out that sedentary occupations carried on in still, warm atmospheres lower basal metabolism, and this tends to stunt growth and predispose the worker to consumption. A suggestive instance is adduced by the U.S. Bureau of Labour Statistics (1915) concerning the mortality of the population of Fall River, one of the great centres of cotton manufacture in America. Tuberculosis is rife, especially among the spinners, and between the ages of 15 and 45 the males have a death-rate from this cause which is 29 per cent above the standard, whilst in the females it is 160 per cent above the standard. The physical labour of cotton spinning is not excessive, but the air of the spinning rooms is very hot and humid. We have seen that potters' shops do not suffer from high relative humidity, but the lack of air movement, the high temperature, and the presence of considerable quantities of moisture in the air (when reckoned in absolute measure), may together be to some extent responsible for the excessive mortality from respiratory diseases shown by the potters In 1900–02 the comparative mortality of potters from phthisis and other respiratory diseases was two to three times greater than that of other males living in the district (Reid, 1910), and though this excessive mortality was doubtless due in large part to the inhalation of pottery dust, it may not have been wholly due to this cause.

It might be thought that hot air and lack of ventilation would conduce to fatigue in the potters, and that evidence of such fatigue might be obtained by investigations on output. Some preliminary investigations were made, but so far as they went they failed to show a definite effect. This may be due to a factor already referred to. All adult potters on piece work have been engaged in the industry for years, and have become acclimatised. If put to work in shops at a temperature of 63° instead of the 70° they prefer, their output might at first fall off rather than increase, as it might take weeks or months before they got used to the healthier conditions. The psychological effects of discomfort, real or imaginary, might retard production appreciably.

Summary.

Most potters' shops show considerably higher temperatures than the shops in other industries such as the boot and shoe and the engineering trades, where the operatives are engaged in active work comparable to that of the potters. Leaf stove and dobbin stove shops were found to be the hottest, their temperature often being over 70° in the winter, and 80° in the summer. At all times it was, on the average, 5° to 9° above what is regarded as reasonable. Some of the shops provided with chamber stoves were equally hot, but others were too cold in winter, their temperature being about 56°. Shops provided with cabinet stoves showed a similar low

temperature in winter, but they were reasonably heated at other times.

The high temperatures were partly due to the action of the potters, as with few exceptions they kept nearly all the windows shut until the shop temperature reached 67° to 70°. This was in spite of the fact that the windows, being usually of the hopper type, caused no direct draughts when in the half-open position. Even at a temperature of 80° only two-thirds of the available window space was kept open.

Contrary to expectation, the air in potters' shops was not found to have a greater relative humidity than that of engineering and of boot and shoe shops, or than outside air at similar dry bulb temperatures; but having regard to the high temperatures met with, the absolute amount of moisture present was considerably greater.

The (median) velocity of the air currents in potters' shops was found to be 17 ft. per min. in winter, and 21 ft. in summer, whilst that of boot and shoe shops was 35 and 37 ft. respectively, or nearly double as much. Consequently the cooling power of the air in potters' shops, as estimated by the kata thermometer, is low, and it averaged only 5·6 and 4·5 for winter and summer observations respectively. That of boot and shoe shops averaged 7·4 and 6·4.

The effective velocity of the air currents impinging on the workers is greatly increased by the body movements made by them when carrying on their industrial operations. The head movements of various classes of workers in the shops generally ranged between 20 and 30 ft. per min., but the mould runners moved 70 ft. on an average.

REFERENCES.

GODLEE UNIVERSITY, MANCHESTER (1916): **Report for 1913-1915.**

HAMBLY, W. D., AND BEDFORD, T. (1921): **Preliminary Notes on Atmospheric Conditions in Boot and Shoe Factories.** *Report No. 11 of Industrial Fatigue Research Board.*

HILL, LEONARD (1919). **The Science of Ventilation and Open Air Treatment.** *Medical Research Council, Special Report Series, No.* 32.

HILL, LEONARD, VERNON, H. M., AND HARGOOD-ASH, D. (1922): **The Kata-Thermometer as a Measure of Ventilation:** *Proc. Roy. Soc.* B. **93.** 198.

RADCLIFFE OBSERVATORY, OXFORD (1891 AND 1911): **Results of Meteorological Observations. 45** and **49.**

REID, G. (1910): **Memorandum on Deaths from Lung Diseases among Workers in the Six Pottery Towns in Staffordshire.** *Report of Departmental Committee on the Use of Lead.* **Cd. 5278.** 71.

TARBELL (1916) : *New Ideas in Business.* 12.

THE ORGANISER (1919) : 196.

UNITED STATES BUREAU OF LABOUR STATISTICS (1915) : *No.* 175 368.

VERNON, H. M. (1922) : **The Index of Comfort at High Atmospheric Temperatures.** (*In course of Publication.*)

WYATT, S : **Atmospheric Conditions in Humid Cotton Weaving Sheds.** *Report to Industrial Research Fatigue Board.* (*In Preparation.*)

TABLE XI.

Relationship between H/θ and Air Velocity in feet per minute.

H/θ	Velocity	H/θ	Velocity.	H/θ	Velocity	H/θ	Velocity	$H\theta$	Velocity.
less than 0·28	formula does not hold	0·37	36	0 48	97	0 59	187	0 70	290
0·28	8	0 38	40	0·49	104	0 60	197	0 71	300
0·29	10	0 39	44	0 50	111	0 61	206	0 72	311
0·30	12	0·40	49	0 51	118	0 62	214	0 73	321
0 31	15	0 41	54	0 52	126	0 63	223	0 74	332
0 32	18	0 42	60	0 53	134	0 64	232	0 75	343
0 33	21	0 43	65	0 54	142	0 65	241	0 76	354
0 34	24	0·44	71	0 55	151	0 66	251	0 77	366
0 35	28	0 45	77	0 56	160	0 67	260	0 78	377
0 36	31	0 46	83	0 57	169	0 68	270	0·79	389
		0 47	90	0 58	178	0 69	280	0 80	401

PART II.—THE EFFICIENCY OF VARIOUS TYPES OF POTTERS' DRYING STOVES.

BY H. M. VERNON, M.D.,
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INTRODUCTION.

We have seen, in the previous report, that most potters' shops are considerably warmer than the workshops of other industries such as the engineering and the boot and shoe industries. Reasons were given for thinking that these high temperatures are bad for the health of the workers, and militate against their efficiency. They are likewise uneconomical, as they imply an unnecessary waste of heat. It is important to decide, therefore, whether such temperatures are unavoidable, having regard to the necessary condition that the stoves should dry the ware and moulds quickly. Cannot means be found for retaining the present drying powers of the stoves, or even of increasing them, and yet of reducing the flood of hot air which passes from them into the shops? In order to obtain an answer to this question, I made numerous observations on the temperature and velocity of the inflowing and outflowing air from various types of stove in the potters' shops of a number of earthenware and china works, and at one works I determined the rate of drying of the ware by means of numerous weighings. In addition, it was necessary to make other investigations before a proper comprehension of the best conditions for drying could be attained.

It is well known (*cf.* Hann, 1915) that the rate at which water evaporates from a moist surface exposed to air at a given

temperature depends on the difference between the maximum tension of aqueous vapour at the temperature in question, and the tension of the aqueous vapour present in the air. The exact relationship between evaporation rate and tension is uncertain, but for practical purposes it may be said that it is approximately proportional to the difference between the dry and wet bulb temperatures of the air, whatever these temperatures may be. Clay and china ware, when freshly made on a jolly, has a thoroughly moist surface, and therefore its initial rate of drying must depend on the difference of the wet and dry bulb temperatures of the air to which it is exposed. As it gets more and more dry, the rate at which it loses moisture must diminish, but it is probable that at all stages of drying this rate varies approximately with the difference of wet and dry bulb temperatures. Hence in all the data to be subsequently described it is assumed that the drying power of the air in a stove is proportional to the difference between its wet and dry bulb temperatures. It depends likewise on the velocity of the air current, though observations to be subsequently described show that this factor is of much less importance in drying than the temperature factor.

Chamber Stoves.

The air conditions in various types of chamber stove were investigated at six works. As a rule the chambers were heated by steam pipes placed a few inches above floor level. In many instances the doors of the stoves were kept open throughout the day (*cf.* Plate I). In others, they were kept open during half or a third of working hours, according as the potter who was using them had two, or three, chambers at his disposal. Quite exceptionally, the doors were kept shut almost all the time.

The air currents in all chamber stoves heated with steam pipes are very similar, when the doors are open There is a current of relatively cool air passing from the shop into the chamber through the lower part of the doorway, and a current of relatively warm air passing from chamber to shop through the upper part of the doorway. At some intermediate position the air neither passes in or out, and this "neutral point" can usually be fixed to an inch or so by means of smoke paper. Instead of a strong in or out draught, the smoke ascends vertically, owing to the hot air rising from the pipes in the stove. The position of the neutral point is affected by a number of conditions, but as a rule it remains fairly steady.

A large number of observations on the temperature and velocity of the air currents were made. The wet and dry bulb hygrometer and the kata thermometer were fixed on a stand placed at various levels in the middle line of the entrance to the chamber.

Badly Ventilated Stoves.

At works H the principal stove consisted of 15 compartments, each 11 ft. in depth, 7 ft. in height, and 20 in. wide between the shelves. The walls of the stove were of rather flimsy wood,

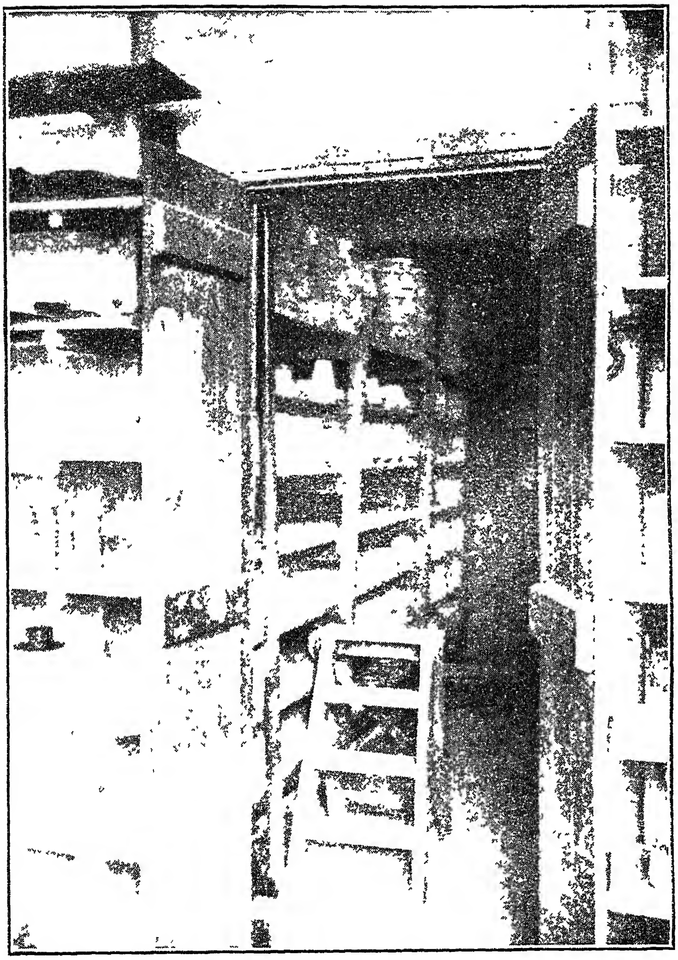

PLATE I —Chamber Stove at Works E

and the partitions between the compartments were incomplete. There was a flat roof to the stove, 6 in. above the top of the doorways, and there were no ventilation pipes whatever when the first series of investigations was made. As a rule the doors of rather more than half of the compartments were kept shut, but they did not fit well, and there was a gap of about an inch at the bottom and three inches at the top. The stoves were used for drying china plates, made on jollies.

Observations were made at the entrance of different compartments on two mornings and two afternoons, and the results were so consistent that only the averages are given in Table I.

TABLE I.

Unventilated Chamber Stoves at Works H (in November).

Level at which air current was tested	15-chamber stove					7-chamber stove.					Gms of water per cubic metre of air entering or leaving		
	Dry bulb.	Wet bulb	Per cent saturation	Drying power.	Velocity of air current	Dry bulb	Wet bulb	Per cent saturation	Drying power	Velocity of air current	15-chamber stove	7-chamber stove	Mean
	°	°			ft	°	°			ft			
3 in from floor	70·4	63·4	65	7·0	67	70·3	62·7	62	7·6	83	12·1	11·6	11·8
1½ ft from floor	70·6	63·4	64	7·2	51	71·0	63·4	63	7·6	61	12·0	12·0	12·0
3½ ft from floor (N P)	74·1	65·4	59	8·7	26	74·9	65·9	58	9·0	28	12·4	12·5	12·4
5 ft from floor	80·9	67·8	47	13·1	58	84·7	70·2	44	14·5	37	12·3	12·9	12·6
6 ft from floor	82·1	68·3	46	13·8	74	87·0	71·1	41	15·9	55	12·4	12·9	12·6
Air in shop	68·9	61·3	62	7·6	25	69·4	61·8	62	7·6	25	11·0	11·2	11·1
Air outside	50·2	47·7	83	2·5	216	50·2	47·7	83	2·5	221	7·9	7·9	7·9

Here it will be seen that whilst the air entering the stove at the bottom had a dry bulb temperature of 70·4°, that passing out a foot below the top had one of 82·1°, or 11·7° higher. Similar observations made at a 7-chamber stove situated in the same shop, with compartments of the same size and construction, showed that the outflowing air had a temperature 16·7° higher than the inflowing air. In that it was issuing at a velocity of 55 ft. per minute from the compartments of this stove, and at one of 74 ft. from those of the 15-chamber stove, it follows that a very large amount of heat was being transferred from stove to shop Other kata thermometer observations show that at the neutral point, which was situated 3½ ft. above floor level in both stoves, the (vertical) air velocity was only about a third as great as the (nearly horizontal) velocity of the air flowing in and out at the bottom and top of the doorways, and about half as great as that of the air measured at intermediate positions.

It will be seen that the drying power of the outflowing air was about twice as great as that of the inflowing air, and about six times that of the air in the yard outside. From the wet and dry bulb temperatures it is possible to calculate the actual weight of moisture in the air, and these values are recorded on the right side of the Table. It will be seen that, on an average,

the outflowing air contained 12·6 grm. of water per cubic metre, as compared with 11·8 grm. in the inflowing air. These are higher values than are usually observed in winter—for the observations were made in November—but the outside air happened to be unusually moist at the time.

It will naturally be said that the rush of hot air from stoves to shop could have been, and ought to have been, prevented by the introduction of suitable ventilator pipes in the roof of the stoves. As a matter of fact, a ventilation system was introduced shortly after the above recorded observations were made. Four pipes were taken from the roof of the 15-chamber stove to louvres on the roof of the workshop, whilst other and larger pipes, concentric to the chamber pipes, led from the roof of the shop to the same louvres. A third set of (smaller) concentric pipes led from the chamber stoves situated in the floor below. The sectional area of the space between the three sets of pipes was such that the ventilation area from the roof of the shop above the stove came to 255 sq. in., and that from the 15-chamber stove itself, to 250 sq in. Hence the total ventilation area from that part of the shop where the stove was situated (forming about a third of the whole length of the shop) was 505 sq. in., or 3½ sq ft. The average area of the space from which hot air was issuing from the stove into the shop—*i.e.*, through the doorways of such compartments as had their doors open, and through the leak holes of such of them as had them shut—was calculated to be about 56 sq. ft., or 16 times more than the ventilator space. It was issuing with considerably smaller velocity, however, as can be gathered from the data recorded in Table II. These figures represent the means of two sets of observations made in the morning and afternoon of a hot summer's day. The average velocity of outflow of hot air from the upper part of the chamber stove doorways was only 31 ft. per min., whilst that of the air passing up the ventilating shafts was over 90 ft. per min. The velocity was ascertained with an anemometer, as the temperature of the air, viz., 94° F., was too high to admit of the use of a kata thermometer, but as there was not sufficient space to allow the air current to impinge on the whole of the anemometer vanes, the true velocity must have been somewhat greater than the

TABLE II.

Ventilated Chamber Stoves at Works H (in July).

Level at which Air Current was tested	Dry Bulb	Wet Bulb	Per cent Saturation	Drying Power	Gms. of Water per cubic metre	Velocity of Air Current.
	°	°				
1½ ft. from floor ..	82·9	72·3	55	10·6	15·2	34 ft.
3½ ft from floor (N P)	84·3	74·2	57	10·1	16·5	14 ft.
6 ft. from floor ..	88·9	76·3	50	12·6	16·6	31 ft
Air in Shop . .	85·4	76·0	60	9·4	17·9	30 ft
Air Outside	76·3	65·1	52	11·2	11·7	204 ft
Air ascending Ventilator Shaft ..	93·9	77·2	42	16·7	16·1	Over 90

figure recorded. The velocity of the air currents flowing up the air shafts from the stoves on the lower floor could be determined accurately, and they were found to average 240 ft. per min. The greater velocity was due to the fact that the shafts were three times the length of those from the upper floor stoves. The temperatures of the shaft air and shop air were 93·1° and 83·5° respectively, or similar to those of the upper floor, so it is probable that the velocity of 90 ft. per min. observed in the air passing up the shafts of the upper floor stoves is not much below the actual value.

It is to be remembered that the velocity of 31 ft. per min. with which the air was passing from the top of the stove doorways into the shop is considerably greater than the *average* velocity with which it was passing through the whole of the upper portions of the doorways and leak holes, so I think we may assume that the hot air from the stoves was passing up the ventilator shafts quite five times more rapidly than it was passing into the shop. Hence it follows that the volume of air passing into the shop, instead of being 16 times more than that passing up the ventilators, was only about three times more. Moreover, its temperature was considerably lower, as it was only 89° when sampled near the top of the stove doorways, whilst that going up the ventilators averaged 94°. It seems probable, therefore, that over a third of the heat which previously passed in the hot air from the stoves into the shop now passed by the ventilating shafts into the air outside.

It does not follow that the removal of a third of the hot air from the stove by means of the ventilators would cause only a proportionate fall in the shop temperature, for it is to be remembered that the ventilator air is replaced by cold air from the outside. When there is no ventilation whatever, the hot air from the stove passes into the upper part of the shop, and then, as it cools and sinks to the lower part, it is sucked back into the stove and heated up again. Owing to this steady and rapid circular movement, it tends to get heated up more and more, whilst the removal of quite a small fraction of the hot air as it is emerging from the stove might have a considerable effect in reducing the average shop temperature. The effect on the shop temperature at works H of removing about a third of the hot air coming from the 15-chamber stove was most distinct, in the opinion of the potters whom I questioned.

In the chamber stoves at several other works the ventilation systems in force were quite inadequate. At works F, each of the three chamber stoves, which were substantial wooden structures used for drying toilet services, had a hood about 2 by 1 ft. just outside and immediately above the doorway. Six-inch pipes led from these hoods to a chimney opening on the top of the building, provided with a louvre. Data recorded in Table III

(the means of observations made in the morning and afternoon) show that hot air was rushing out of the upper part of the doorways with a velocity of 139 ft. per min. The velocity of the air currents in the ventilator shafts was tested by means of an anemometer, and was found to average 122 ft. per min., or distinctly less than that from the doorways. On testing the air currents emerging from the upper part of the doorways with smoke paper, it was found that none of the smoke passed into the ventilator hood until the paper was one inch below the top of the doorway or one inch below the level of the hood. It rushed horizontally into the shop, and it was calculated that not more than three per cent. of the total hot air passing from the stoves went up the ventilator.

In another shop, where the chamber stoves were used for drying mugs and jugs, the temperature of the stoves was lower, and the velocity of air movement at the entrance of the chambers was less (*see* Table III). The ventilator hoods over the doorways were similar to those mentioned above. From smoke tests, and from determinations of the velocity of the air currents in the ventilator shafts, it was calculated that less than a tenth of the hot air issuing from the chambers passed into the ventilators.

TABLE III.

Chamber Stoves at Works F.

Level at which Air Current was tested.	Toilet set stoves.						Mug and jug stoves.					
	Dry Bulb	Wet Bulb	Per cent Saturation	Drying Power.	Velocity of Air	Grams of Water per cubic metre	Dry Bulb	Wet Bulb	Per cent Saturation	Drying power.	Velocity of Air Current	Grams of Water per cubic metre
	°	°			ft		°	°			ft	
1 ft. from floor ..	62·7	56·0	64	6·7	97	9·3	65·8	60·9	73	4·9	85	11·8
3 ft. or 3 ft 5 in (N.P.)	72·9	63·7	57	9·2	50	11·7	73·6	67·6	70	6·0	23	14·5
5 ft. 8 in .	91·9	69·3	29	22·6	135	10·6	78·7	69·8	60	8·9	58	14·6
Air in shop	61·3	54·5	63	6·8	22	8·7	67·9	62·5	71	5·4	11	12·3
Air outside . .	44·1	40·9	76	3·2	198	5·8	44·1	40·9	76	3·2	198	5·8

The data in Table III need a few words of explanation, as they appear to be somewhat inconsistent. The air passing out of the toilet set stoves was 29·2° warmer than the inflowing air, and yet the temperature of the shop was only 61·3°, or 6·6° lower than the average temperature of the other shop, in spite of the fact that the outflowing air from the stoves in this shop was only 12·9° warmer than the inflowing air, and was emerging at less than half the velocity. The reason was that the toilet set shop had a much larger proportion of its windows open, and it had, in addition, three doorways which gave good cross currents. The drying power of the air emerging from the toilet

set stoves was two and a half times greater than that from the mug and jug stoves, because of its high dry bulb and relatively low wet bulb temperature. The actual weight of water present in the air was considerably less than in that from mug and jug stoves, and, somewhat unexpectedly, the water in the outflowing air was less than that in the air at the neutral point of the stove entrance. Presumably this was owing to its much greater velocity of movement. The more slowly moving air at the neutral point had time to pick up more moisture.

Well Ventilated Stoves.

The chamber stove of a third shop in works F had a simple but distinctly efficient ventilation system. The stove was 7 by 11 ft. in area, and $9\frac{1}{2}$ ft in height, and at the top of the doorway, just *inside* the chamber, there was a rectangular shaft 19 by 11 in., and about 11 ft. in height, opening on the outside by means of a louvre. The doorway of this stove was $6\frac{1}{2}$ ft. in height, and the neutral point was 4 ft. 4 in. above floor level.

On testing with smoke paper the upper 26 in. of the doorway through which hot air was emerging, it was found that when the paper was held vertically below the inner edge of the shaft and 12 in from it, the smoke just avoided passing up the shaft and all emerged into the shop, but if held anywhere nearer to the shaft it ascended it. In that the velocity of air current up the shaft was slightly greater than that passing into the shop, it was calculated that approximately half of the hot air from the stove passed up the ventilator and half into the shop As an average of two sets of observations, it was found that the outflowing air from the stove had a temperature of 83·0° and a drying power of 15·0, the corresponding figures for the inflowing air being 65·6° and 4·9. The velocities of inflow and outflow were 152 ft. and 106 ft. respectively

At three other works the chamber stoves investigated had efficient systems of ventilation provided, though it was the exception, rather than the rule, for the ventilators to be utilised. The most efficient system of ventilation observed in any stove, either of a chamber or any other pattern, was at works G, where electric fittings were manufactured. The chamber stove was a large brick-walled structure, about 43 by 23 ft. in floor area, 8 ft. high at the sides, and 16 ft. high in the middle. At one end it had two doorways, each 7 by 3 ft., which opened on to the shop, and at the other end it had two more doorways of similar size, one opening to the outside air, and the other opening on to a passage. In the roof there was a double flap ventilator, and when the flaps were raised there was a clear opening to the outside of eight sq. ft. Another ventilator on the end wall had an area of three sq. ft. In winter time the door opening on to the outside air was kept shut, but the other three doors were kept open during working hours. The following records

were obtained at one of the two doorways opening on to the shop :

TABLE IV.

Chamber Stove at Works G (in December).

Level at which Air Current was tested.	Ventilators shut					Central Ventilator open.				
	Dry Bulb	Wet Bulb	Per cent Saturation	Drying power	Velocity of air current	Dry Bulb	Wet Bulb	Per cent. Saturation	Drying power.	Velocity of air current
	°	°			ft	°	°			ft
8 in above floor	66 0	59 2	65	6 8	106	—	—	—	—	—
2 ft above floor	66 6	60 0	66	6 6	80	—	—	—	—	—
3 ft. above floor (N P) .	66 5	59·5	64	7·0	77	—	—	—	—	—
5 ft. above floor . .	89 8	70 2	34	19 6	86	69·7	61·7	60	8 0	45
6½ ft above floor .. .	98 3	76 3	32	22 0	—	—	—	—	—	—
Air in shop .	65·2	59 9	71	5 3	35	—	—	—	—	—

The neutral point was 3 ft. above floor level, and the air emerging 1 ft. below the top of the doorway was 32·3° warmer than the inflowing air. The velocity of this flow could not be ascertained by kata readings, owing to its high temperature When the central ventilator was opened (but not the end one), the neutral point rose to 5 ft. 3 in., and the temperature of the air at the 5 ft. level fell 20°. That is to say, instead of hot air passing into the shop through the upper 4¼ ft. of the doorways, it now passed through only 2 ft., and such as did emerge probably did not amount to a third of its previous volume, for its velocity was much lower.

In the summer (July) I found that both the end ventilator and the central one were kept open during working hours, whilst the fourth door, opening on to the air outside, was kept open in addition. Smoke paper tests showed that, as a rule, there were no outflowing currents of hot air through any of the four doorways, though occasionally hot air passed outwards for a few seconds through the upper part of one or two of the doorways. Evidently the ventilators were large enough to carry away almost all the hot air rising from the steam pipes. Anemometer readings showed that air was passing out through the ventilator on the end wall at a rate of 78 ft. per min., but the opening was louvred, whilst that in the centre was absolutely clear of obstruction, and must therefore have carried off the air at a more rapid rate. Temperature observations made inside the stove, near its centre, showed that its drying powers were rather less than those observed in winter time.

	Dry Bulb.	Wet Bulb	Per cent Saturation	Drying Power.
	°	°		
At 2 ft. above floor level ..	83·5	72·9	55	10·6
At 5 ft. ,, ,, ,, ..	89·1	76 0	49	13·1
At 7 ft. ,, ,, ,, ..	93·9	73 7	35	20·2
Air in shop	75·7	69 9	70	5 8
Air outside	66·5	63·6	83	2·9

As far as I could gather, it was only in the warmest months of the year that both ventilators were kept open, so it is probable that as a rule a fair amount of hot air passed back from the stove into the shop. During the winter experiments the foreman in charge did not care to have even the central ventilator open long enough for me to make a complete set of observations. He explained that in order to dry the electric fittings heat was the one thing necessary, and that ventilation was unimportant. At night time all the doors and ventilators were shut, and the temperature of the stove—which was heated by horizontal and vertical systems of steam pipes—rose to something between 100° and 140° F.

At another works, B, a system of ventilation on modern principles had been installed. A 24-in. shaft drew air from two to five pentarcomb openings in each of six shops, and the shops contained, between them, 9 dobbin stoves and 9 chamber stoves. By means of a small door situated just above the level of the fan it was possible to obtain access to the shaft, and the air currents in it were investigated by kata thermometer and anemometer. During these observations the door could not be completely shut, but it never fitted well, and it gaped no more at the times the observations were being made than at other times. Kata observations made during the winter time showed an average current of 210 ft. per min. up the shaft when the fan was not on, and one of 933 ft. when it was on. Anemometer observations made during summer time yielded similar values, as can be gathered from Table V. This Table records the averages of the observations made during the course of two days. On the first day, the fan was running between 11 and 1 p.m., and again from 2 to 5.30, but on the second day it was not running at all. Readings of air velocity and temperature were taken every 40 minutes in the ventilator shaft, whilst those in the shops and the yard outside were made on four occasions during the course of the day.

TABLE V.

Comparison of Air in Shaft with that in Shops at Works B.

	Air tested	Dry Bulb	Wet Bulb	Per cent saturation	Drying power	Grm of water per cubic Metre.	Increase of Water over that in Air outside.	Velocity of Air Current.
		°	°					ft.
July 25th.	Air of Shaft with Fan off	89 2	77 2	52	12 0	17 4	5·3	259
	Air of Shaft with Fan on	90 4	76 9	49	13·5	17·0	4·9	959
	Air emerging from Stoves (3 Shops)	92 3	76 9	44	15·4	16·1	4·0	—
	Air entering stoves (3 Shops)	79 6	70 5	59	9·1	14·7	2 6	—
	Air on Benches of all Shops	79 0	69·6	58	9·4	14·2	2·1	47
	Air outside	73 8	64 6	58	9 2	12·1	—	335
July 26th.	Air of Shaft with Fan off	85·0	69 7	42	15 3	12·4	3·4	265
	Air on Benches of all Shops	72 3	62 1	53	10 2	10·5	1·5	45
	Air outside	67 3	57 4	53	9·9	9 0	—	257

The temperature of the shaft air was about the same whether the fan was on or off, and it corresponded roughly with that

of the air emerging into the shops through the upper part of the stove doorways, though no exact comparison is possible as observations were made only on half of all the stoves which supplied air to the shaft.

When the fan was on, the shaft air contained 4·9 grm. of water per cubic metre in excess of that found in the air outside, and—the velocity of the air current in the shaft being known—it was calculated that the total weight of water extracted from the ware drying in the stoves amounted to 418 grm. (or 15 oz.) per min. What proportion does this represent of the total moisture coming from the drying ware? No exact estimate was possible, but I made a very rough one in the following way. At another works (E) I enumerated approximately the plates and saucers made each day by a group of seven potters, and I determined the loss in weight which samples of these plates underwent in drying. I thereby was able to calculate that the total loss in weight averaged about 70 grm. per min. from the plates made by each potter. At works B the potters were making toilet services and cups in addition to plates, but supposing that the articles made yielded the same amount of moisture per potter as that mentioned, it would follow that the ware from all the shops ventilated by the shaft would yield about 750 grm. of water. I lay no stress on this figure, because of the doubtful data on which it is calculated, but I think it may be concluded that in all probability the ventilator extracted half, or over half, of the moisture given off by the drying ware.

When the ventilator fan was not running, the air passing up the shaft contained 5·3 grm. more moisture per cubic metre than the outside air on one day, and 3·4 grm. more on the next day. Taking an average of the two values, it can be calculated that the shaft was extracting 101 grm. of water per min This is only a quarter as much as when the fan was running, and probably about a seventh of the total amount evaporating from the drying ware. Hence it might be thought that the fan ought to have been kept running at all times, if efficient ventilation were required. As a matter of fact, it was never kept on in the winter months, and only on hot afternoons in the summer, as the men found that it stopped their ware from drying properly and reduced their output considerably. The reason of this was indicated when discussing the chamber stoves at works G. The steady removal of even a relatively small volume of hot air from the upper part of the stoves may cause a considerable fall in the temperature of the stoves and of the shops, though it may not have much influence in reducing the amount of back draught into the shops. In the present instance, the ventilating shaft removed about 3,000 cubic ft. of hot air per min. when the fan was on, and from observations on the velocity of the air currents emerging from the stoves, and the area of doors and leak holes through which they emerged, it was calculated that this volume probably represented something like a third of the total back draught air. It

might be thought that the removal of such a substantial fraction of the back draught air would have the effect of raising the neutral point of the air currents passing in and out of the stove doors by a considerable amount, but it did not appear to do so. Two to four observations were made at the stove doors in four shops shortly before and shortly after the fan was set running, and on an average the height of the neutral point was raised only an inch. Probably the air emerged from the stoves at a lower velocity when the fan was running, but I had no time to estimate it, as I was fully occupied over other observations.

Attempts were made to ascertain the effect of running the fan on the temperature of the shops, but the results obtained were too irregular to be worth recording. This was owing to the variations in the amount of steam supplied to the stoves on different days and at different times of the day. It is self-evident, however, that if the fan, when running, removed 3,000 cubic ft. of hot air per min , whilst the shaft without the fan removed only a fourth this volume, the effect must have been considerable. On the summer days when observations were made the temperature of the air in the shaft was 17° higher than that of the outside air, and on the winter days, 39° higher.

The difficulty of combining adequate drying of the ware in the stoves with good, or even fair, ventilation was met with over and over again. The above-described stoves at works F, where the hood ventilators removed only a tenth of the outflowing air, had additional ventilation pipes inside at the far end, but the men stopped them up, in order to hasten the drying of their ware. Again, at works E there were a number of chamber stoves, about $10 \times 7\frac{1}{2}$ ft. in area, and 11 ft. high, and each of these stoves had a ventilator space 18×12 in. in size, which led to rectangular brick shafts some 30 ft. high and 24×28 in. internal measurement. The air velocity in one of the shafts was found to average 280 ft. per min. under ordinary conditions, and it was calculated that if the ventilators had been fully open, it would have extracted about half of the hot air which was otherwise passing into the shop. As a matter of fact, the ventilators were fitted with badly designed wooden gratings, which, even when open, stopped up three-fifths of the ventilation area. In addition the men, both in winter and in summer time, kept about half of the gratings shut completely, so their practical effectiveness was very small.

Efficient Stoves.

By efficient stoves I mean stoves which dry the ware well, and at the same time allow comparatively little of their heat to pass into the shops; *i.e.*, stoves which are efficient both from the mechanical and the human aspect of the industry. The above-described stove at works G fell in this category when its ventilators were kept open, but those at works B did not do so even when the fan was running. Most chamber stoves would likewise fall in the category if their doors were generally

kept shut, but in my experience they were much more frequently open than shut during working hours. The chamber stoves at works E had doors with double hinges, which caused the doors to swing back automatically to the closed position, but the potters found that it was too much trouble to have to open them each time they went in and out of a stove, so they kept them propped open all day. This continuous propping had in most instances damaged the hinges, so that they no longer caused automatic shutting when the props were removed.

The only chamber stoves I met with which complied with my definition of efficiency were those at two china works. They were heated by means of coke-burning stove-pots of the ordinary type, and such stove pots, which generally have a long flue pipe up which the very hot air from the stove has to pass, extract a very large amount of air from the drying chambers in which they are placed. Even this suction is not sufficient to prevent hot air from passing into the shop if the doors of the chamber are open, but they prevent a great deal of it. When the doors are shut, even if they fit badly and show gaps of several inches at top and bottom, there is a strong in-draught of air at every gap, whilst most other chamber stoves show the usual outflow of hot air through any leak holes in the upper part of the stoves.

In china casting it is the custom to get the moulds as dry and warm as possible, and after removing a pile of them from the stove, to fill them with china slip one to four times successively at brief intervals. They are then returned to the stoves for—as a rule—24 hours, when the process is repeated. Periods of casting alternate with periods of fettling of the cast ware, so the workers do not need to visit their stoves nearly so frequently as those engaged in producing earthenware articles. In consequence it is their habit to keep the doors of their stoves shut, and thereby the temperature is kept up and very little hot air passes back into the shops. Series of observations made on four stoves at works K illustrate these statements. In one shop were two chambers, each $10\frac{1}{2} \times 10$ ft. in area, and 8 ft. in height, and the observations recorded in Table VI were made when the

TABLE VI.

Chamber Stoves at Works K.

Level at which temperature was tested.	1st stove					2nd stove				
	Dry bulb	Wet bulb.	Per cent saturation	Drying power	Gm of water per m³	Dry bulb	Wet bulb.	Per cent saturation	Drying power	Gm of water per m³.
	°	°				°	°			
1 ft. above floor	82·3	66·4	40	15·9	10·8	98·3	80·3	40	18·0	17·4
2 ft. above floor . ..	—	—	—	—	—	101·3	83·1	45	18·2	21·3
4 ft. above floor . ..	96·3	76·3	35	20·0	14·4	104·3	85·9	45	18·4	23·3
6 ft. above floor	95·3	75·3	35	20·0	14·0	101·3	83·1	45	18·2	21·3
Air in shop . .	56·5	52·0	73	4·5	8·6	56·5	52·0	73	4·5	8·6
Air outside ..	45·2	43·2	85	2·0	6·7	45·2	43·2	85	2·0	6·7

doors were shut. They show that a high and steady temperature was maintained at all levels 2 ft. or more above the floor. Though the temperature was about 100° that of the shop was only 56·5°. It was, in fact, distinctly too cool for comfort. The wet bulb temperature was likewise high, and the air carried a good deal of moisture, but nevertheless its drying power was above the average, owing to the high dry bulb temperature.

The observations recorded in Table VII were made in two other chamber stoves at works K. Those on the left do not indicate a very high stove temperature or great drying power, but on two other occasions the dry bulb temperature at 4 ft. above floor level was found to be 95° to 97°, and the wet bulb 77° to 81°, so the drying power was 16 to 18. The air in the shop was distinctly too cold for comfort, and I was told that there was an independent heating system in the shop, but it was not in working order. There was likewise an independent heating system in the ground floor shop, and this was in working order.

Table VII.

Chamber Stoves at Works K (with Shop capable of being independently heated).

Level at which temperature was tested	1st Floor Shop.					Ground Floor Shop.				
	Dry bulb	Wet bulb	Per cent saturation	Drying power	Gm of water per m³.	Dry bulb	Wet bulb	Per cent saturation	Drying power	Gm of water per m³
	°	°				°	°			
1 ft above floor . .	74·0	62·1	48	11·9	10·0	77·5	67·2	55	10·3	12·9
2 ft. above floor .	78·5	68·4	56	10·1	13·5	82·8	71·4	53	11·4	14·6
4 ft. above floor .	81·7	72·2	59	9·5	15·7	84·9	73·9	55	11·0	16·2
7 ft. above floor ..	83·5	72·7	55	10·8	15·5	87·0	73·6	48	13·4	15·1
Air in shop .	52·5	49·9	82	2·6	8·5	62·6	58·6	77	4·0	11·2
Air outside	46·6	45·0	89	1·6	7·4	46·4	45·0	90	1·4	7·5

but the potters preferred not to make use of it. They usually kept the door into the stove partly open, but even when 12 inches ajar it did not let any hot air into the shop, so great was the suction power of the stove-pot. The stove itself was a brick-walled structure, 23 × 36 ft. in area, and 12 ft. in height, and it was used for drying cup moulds. It will be gathered that of all the chamber stoves described, it alone, with its independently warmed shop, came nearest to the desired standard of efficiency. Even it appeared somewhat deficient in drying power, for a similar value to that recorded in the Table, viz 13·4, was observed on two other occasions in the winter, though a value of 17·9 was observed in the summer. This defect could have been remedied by greater care in keeping the door shut, for it was found that when the door was wide open hot air passed out through the upper third of the doorway.

Dobbin Stoves.

Badly Ventilated Stoves.

The dobbin stoves investigated fall into two of the three classes described for chamber stoves, viz., the badly ventilated and the well ventilated, but none of them could be described as efficient, in accordance with the definition of efficiency given. Almost all of the dobbins observed were of the usual hexagonal form, though a few of them were two-sided. At works F a shop about 66 × 32 ft. in area contained two dobbin stoves, each 7 ft. in width and 32 ft. in length. In each stove there were four hexagonal dobbins, the double doors of which were 2 ft. in width and 7 ft. 3 in. in height. During working hours the doors of half of all the dobbins were kept open. There was a strong in-draught of cooler air in the lower half of each entrance, and a strong out-draught of warmer air in the upper half. The neutral point was fairly steady at the various entrances, and ranged from 3 ft. 3 in. to 4 ft. 2 in. above the bottom of the doorway, or 4 ft. to 3 ft. 1 in. below the top. In Table VIII are recorded the means of two sets of winter observations, made in the morning and afternoon of successive days, and one set of summer observations.

Table VIII.

Dobbin Stoves at Works F.

Level at which temperature was tested.	Winter observations					Summer observations			
	Dry bulb	Wet bulb.	Per cent saturation.	Drying power	Velocity of air current.	Dry bulb	Wet bulb.	Per cent. saturation.	Drying power
	°	°			ft	°	°		
6 in above entrance	72 5	64 5	61	8 0	55	73·8	62 2	49	11 6
3½ ft above entrance (N.P.)	79 9	68 8	53	11 1	14	—	—	—	—
5 ft above entrance	96 8	77 0	35	19 8	—	90 5	73 1	39	17 4
6½ ft above entrance	105 2	77 6	26	27 6	94	109·8	81·4	24	28 4
Air in shop	70 2	61·7	59	8·5	29	75·1	64 8	54	10 3
Air outside	48·2	45·2	79	3 0	142	65·6	55 3	50	10 3

It will be seen that in the winter observations the outflowing air near the top of the doorways had a temperature of 105·2°, and a drying power of 27·6. This was the maximum value observed in any type of stove in the winter, but still higher values were observed in the summer. Thus the Table under discussion records a drying power of 28·4, and other observations showed a dry bulb temperature of 123°, and a drying power of 32·2. The velocity of the outflowing air was determined (in the winter observations) from the rate of *warming* of the kata thermometer between 95° and 100°, but the determination cannot be regarded as very reliable.

The doorways of the dobbin stoves were exceptionally high, and it occurred to me that if, when the mould runners were filling

the lower shelves of the dobbins, the upper portions of the doorways were closed, a certain amount of the hot air would be prevented from flowing back into the shop. At my suggestion the works manager was good enough to have one pair of doors cut horizontally across, 27 inches from the top. Extra hinges were provided, and thereby it was possible to open the lower 60 inches of the doors and leave the upper 27 inches closed. However, the closure of the upper doors seemed to have but little practical effect in reducing the amount of back draught air. Careful determinations of the neutral point showed that when the whole length of doors was open, this point was 37 inches below the top. When the upper (27-in.) doors were closed, and the lower ones kept open, the neutral point was found to be 38 inches below the new top of the doorway, so the area through which the hot air emerged was as great as before, though it is possible that the velocity of emergence was less. The temperature of the emerging air was found, on each of the two occasions on which it was tested, to be somewhat lower when the upper doors were shut, the average temperature observed being 115·2° as against 119·6°, but I do not think that this fact, even if it held regularly, is sufficient to invalidiate the conclusion that but little of the back draught was prevented by the closure of the upper doors. The only effective method of reducing the back draught would have been to reduce the area of the leak holes between the revolving dobbins and their frame. There was a gap of 2 to 4 inches between the edges of the dobbins and the framework of the doorways, whilst there was a gap of 6 to 10 inches between the top of the dobbins and the stove roof above.

The ventilation of the two dobbin stoves was so small as to be negligible. Each stove had a 7-in. square pipe passing up from the middle of its flat roof. One of these pipes opened into a small loft above the stove, whilst the other passed to the roof outside, but I found it to be closed up entirely. Hence the whole of the heat from the stoves found its way into the shop, and a set of nine observations, made at various times on five days in winter time, showed that when the air temperature outside was 40° to 50°, that in the shop was 69·5°. Again, eight observations, made in summer time when the outside air temperature averaged 63°, showed a mean shop temperature of 77°.

In the dobbin stove shop of works K there were 22 two-sided dobbins, each $9\frac{1}{2}$ by $3\frac{1}{2}$ ft. in size. The dobbins fitted their frames fairly well, but the air leaking through gaps near the top was tested on five occasions in winter time, and found to have a temperature ranging from 103·3° to 109·3°, and a drying power of 25·0 to 29·0 (average, 26·5). The stove had no ventilation pipes whatever, but the workshop had one 5-in. ventilating pipe opening into a hood (2 ft. in diameter) situated $7\frac{1}{2}$ ft. above floor level. The air draught in this pipe, together with that of three others from fettling cupboards, was induced by a small propeller fan. Smoke tests showed that it was too weak to have a

substantial effect on the ventilation of the shop. Still, the shop was not so warm as that at works F, for seven observations made when the outside temperature averaged 44·5° gave the reasonable shop temperature of 65·3°.

Well Ventilated Stoves.

In the three other works at which dobbin stoves were investigated, the systems of ventilation might be described as good, though they were not able to prevent very large amounts of hot air from passing into the shops. At works B the dobbin stoves in three shops were investigated. The dobbins were of the usual hexagonal type, and one of the shops contained five of these stoves, whilst the other two contained two each. The results of the winter observations in two of the shops are recorded in Table IX, those in the saucer makers' shop being the mean of

TABLE IX.

Dobbin Stoves at Works B.

Level at which temperature was tested.	Saucer Makers' Shop						Plate Makers' Shop.					
	Dry bulb	Wet bulb	Per cent saturation	Drying power.	Velocity of air current	Gm of water per m³	Dry bulb	Wet bulb	Per cent saturation	Drying power	Velocity of air current	Gm of water per m³
	°	°			ft		°	°			ft	
9 in above entrance .. .	72·7	67·7	74	5·0	44	14·9	66·2	59·2	64	7·0	48	10·5
3 ft 2 in. above entrance (N P)	77·3	72·0	74	5·3	12	17·2	68·7	62·7	68	6·0	45	12·0
4½ ft. above entrance (N P) ..	—	—	—	—	—	—	74·5	68·7	71	5·8	10	15·1
5½ ft. above entrance .. .	—	—	—	—	—	—	84·8	73·4	53	11·4	30	15·5
6½ ft or 7½ ft above entrance	92·3	76·3	43	16·0	—	15·8	92·8	75·8	41	17·0	—	15·3
Air in shop .. .	73·0	66·7	69	6·3	13	14·1	67·5	60·3	63	7·2	13	10·7
Air outside .. .	40·0	38·2	85	1·8	178	5·6	41·7	39·6	84	2·1	163	5·9

two sets of data. The doorways to the stoves of the saucer makers' shop were 8 ft. in height and those in the plate maker's shop were 7 ft. The neutral point in the stoves of the first of these shops averaged 3 ft. 2 in. above the bottom of the doorway, and that in stoves of the other shops 4½ ft. Consequently hot air, at a temperature of 85° to 93°, was emerging into the shops from these dobbin stoves through spaces averaging 3 ft. 8in by 27 in. in area. The effect on the atmosphere of the shops may be gauged by the fact that their temperature was 73·0° and 67·5° respectively at the time the observations were made. The velocity of flow of this hot air could not be ascertained by means of the kata thermometer, but it was probably about 50 ft. per min.

In the summer the temperature conditions in the shops were relatively better than in the winter, as the shop temperature averaged only 79° when the air outside was at 74°. The temperature of the air emerging from the stoves into the shop averaged 90°, so it was rather less than in the winter. Its drying power was likewise less, being from 11·7 to 13·1, as against the values of 16·0 to 17·0 observed in the winter.

The ventilation of these dobbin stoves has already been referred to. It consisted of pentarcomb openings, 17 × 5 in. in size, fixed inside the stoves just above each of the doorways. It was pointed out that when the ventilation fan was running it probably removed about a third of the back draught air and over half of the total moisture from the drying ware, but when it was not running, as was usually the case, the effect was only a fourth as great as this.

Further evidence of the comparatively small effect even of large ventilators on the outflow of hot air from badly constructed dobbin stoves was obtained at works A. A stove 60 ft. by 12 ft. in area, and 9½ ft., high in front, with a sloping roof rising to 14 ft. in the middle, had three ventilators, each 15 in. in diameter. These ventilators opened in the roof on to short pipes, covered with a cowl. On testing the neutral point at the doorways of the five hexagonal dobbins of the stove, it was found to be, on an average, 3 ft. above floor level when the ventilators were shut, and 3 ft. 9 in when they were open, As the doorways were 6½ ft. high it meant that when the ventilators were open hot air was pouring out in the shop from a 33 in. space instead of a 42 in. space The effect of opening the ventilators on the state of the air in the shop was, however, most distinct. Ten minutes after the opening, the dry bulb temperature on the working benches had fallen from 67·7° to 66·8°, and the wet bulb from 60·1° to 58·2°, whilst the velocity of the air currents had increased from 14 ft. per min. to 25 ft. If the ventilators had all been kept open, the temperature of the air in the shop, and likewise in the stoves, would doubtless have fallen many degrees.

Another shop, with a similar type of stove, showed a somewhat smaller effect on opening the ventilators. In all the dobbin stoves in both shops every facility was afforded for the creation of back draught. There were gaps of 4 to 9 in. (7 in. on an average) between the edges of the dobbins and the framework of the doorways, and plenty of space for the escape of hot air at the top of the dobbins.

TABLE X.

Dobbin Stove at Works D.

Level at which conditions were tested	Winter Observations.					Summer Observations.			
	Dry bulb	Wet bulb	Per cent. saturation	Drying power	Velocity of air current.	Dry bulb	Wet bulb.	Per cent. saturation.	Drying power.
	°	°			ft	°	°		
8 in. above entrance	74 1	62 3	49	11 8	85	76 5	64 3	49	12 2
2 ft 3 in above entrance (N P)	77 1	64 1	47	13 0	20	—	—	—	—
5 ft above entrance .	88 6	67 3	31	21 3	63	104 3	74 4	24	29 9
Air in shop	71 5	59 3	47	12 2	22	75 0	65 0	55	10 0
Air outside .	47 3	42 0	65	5 3	477	67 0	56 1	49	10 9

At works D there was a single stove with three dobbins, and inside the entrance of each doorway there was a large vertical shaft, 14 ft. in height, with louvre openings above the roof outside. These ventilators were always kept open, and observations made in summer time by means of an anemometer showed that they removed considerably more than half of the back draught air emerging from the stove. Thus the velocity of the air current passing up the shafts averaged 240 ft. per min., whilst that of the air issuing from the upper portion of the stove doorways was only 50 ft. per min. It issued through a somewhat larger area, as the doorways were 2 ft. wide, and the neutral point was, on an average, $1\frac{3}{4}$ ft. from the top, whilst the ventilating shafts were 2 ft. by $1\frac{1}{2}$ ft. in area. Because of the effective ventilation, the temperature of the shop was found to be only 8° higher than that of the air outside, in spite of the fact that such air as did emerge from the stove had a temperature of 104°.

Three out of the four windows in the shop were open when the summer observations were made, and this probably accounted for the good ventilation When the winter observations were made, three out of the four windows were shut, and it was found that half or less than half of the back draught air was passing up the ventilating shafts. Observations made on two days showed that the neutral point was 3 to $3\frac{1}{2}$ ft. from the top of the doorways, instead of $1\frac{3}{4}$ ft., and the hot air was issuing with a greater velocity than in summer. In consequence, the temperature of the air in the shop was only 3 5° lower than that observed in the summer, although the air outside was 20° cooler. The shop was a very narrow and overcrowded one.

Draw-Out and Leaf Stoves.

Stoves of these two related types were investigated at two works. In all of them the ventilation was good, though it did not prevent the passage of a great deal of hot air into the shops, and their consequent overheating. At works E there were three draw-out stoves, all of quite recent construction (*cf.* Plate II). Most of the observations were made on the largest of them. This stove, 24 by $15\frac{1}{2}$ ft. in area, contained 10 sections each side. Each section was 10 ft. high, $6\frac{1}{2}$ ft. deep and 2 ft. wide, and was suspended on wheels which ran on girders. The sections could be pulled out separately, and when fully pulled out the back board usually fitted so closely in the gap as to prevent any leakage of hot air. The sections likewise fitted accurately to their framework when they were pushed home, but in any intermediate position there were very large possibilities of hot air leakage. The potters were rather careless in seeing that the sections were either pulled out to their full extent, or pushed right home. Also, one or two of the sections did not fit well, or had parts of their back boards missing, whilst there were small gaps at the tops of the sections, near the girders, and I found

that, on an average, having due regard to the neutral point of the air currents, hot air was leaking into the shop through spaces which together amounted to 19 sq. ft. By means of cardboard and of several thicknesses of brown paper I was myself able to reduce the leakage area to 11 sq. ft., and it could, without difficulty, have been reduced to considerably less. In fact, almost all the leakages could have been avoided except those due to the carelessness of the potters, but these might average about 6 sq. ft. during working hours. This is a very small area, as it is rather less than the leakage area from a single dobbin of the usual type of dobbin stove, which was found to be 6, 7, 7, 7, 8 and 9 sq. ft. in the various instances in which it was measured. The draw-out stove dried the plates and saucers produced by six potters, and as such potters usually require two—or occasionally three—dobbins each, it means that the draw-out stove was equivalent to at least 12 dobbins, and the doorways of these dobbins would have an average leakage area of 90 sq. ft. Hence, even at its worst, the draw-out stove was an enormous improvement on dobbin stoves in respect of hot-air leakage.

The ventilators of the stove were two in number. Each had an area $1\frac{1}{2}$ ft. by 1 ft, but they were fitted with wooden gratings which, even when open to their fullest extent, blocked up three-fifths of the space Consequently the total ventilation area was only 173 sq. in., or a sixteenth of the leakage area. Each ventilator opened into a brick shaft of $4\frac{2}{3}$ sq. ft. sectional area (internally), which ascended some 20 ft to the roof of the building. One of these shafts had wooden planking in one place, and by the kind permission of the management I was allowed to remove a plank and sample the air in the shaft. The opening was closed before and after the introduction of the instruments, so as to keep the conditions constant. The velocity of the air current was ascertained by an anemometer, which was fixed in a light wooden framework and placed in the centre of the shaft. It was allowed to run for two to three minutes at each test, and the results were very consistent. The average velocity was 277 ft. per min., whilst the velocity of hot air flowing out through the leak holes at the top of the stove into the shop was 98 ft. per min. The average velocity of leakage into the shop through the whole of the leakage area was probably only a half to two-thirds this figure, so hot air was passing up the shaft some four to six times quicker than it was passing into the shop. Supposing that it passed up each of the two shafts five times quicker, it would follow that the total volume of air ascending the shafts would be nearly two and a half times as great as that passing out by leak holes into the shop. It was practically impossible for all this volume of air to rush through the stove ventilators, obstructed as they were with wooden gratings, and I believe that much of it, and perhaps the larger part, passed directly through the pores of the brickwork of the shafts, which ascended through the middle of the stove.

The shafts received hot air from other (chamber) stoves besides the draw-out stove in question, but I shut off their ventilators before taking the anemometer readings.

Data showing the temperature of the air circulating in the stove are recorded in Table XI. In order to obtain these figures, one of the sections was pulled out about four inches from its frame, and the hygrometer was applied to the gap. The winter data are the means of two sets of observations, made in the morning and afternoon, whilst the summer data are the means of six sets of observations.

TABLE XI.

Draw-out Stove at Works E

Level at which Temperature was tested.	Winter Observations					Summer Observations				
	Dry Bulb.	Wet Bulb.	Per cent Saturation	Drying Power.	Gm of water per m³	Dry Bulb.	Wet Bulb	Per cent Saturation	Drying Power.	Gm of Water per m³
	°	°				°	°			
10 in. from bottom ..	67·3	58·5	57	8·8	9·6	76·1	67·0	59	9·1	13·2
3½ ft from bottom .	75·7	65·4	54	10·3	12·0	—	—	—	—	—
5 ft. from bottom (N.P.)	88·3	73·8	44	14·5	14·3	—	—	—	—	—
7 ft from bottom .	98·0	75·0	30	23·0	13·0	—	—	—	—	—
8½ ft from bottom .. .	102·8	75·5	·25	27·3	12·3	99·6	79·7	36	19·9	16·3
Air in shop	76·0	64·7	51	11·3	11·4	78·0	68·5	57	9·5	13·6
Air outside	45·7	43·0	81	2·7	6·6	67·4	61·9	71	5·5	12·1

It will be seen that there was a steady rise in the temperature of the air from the bottom to the top of the section. At the highest level investigated, which was 1½ ft. from the actual top, the back draught air had a temperature of 100° or more, and a drying power of 20 to 27. The temperature and drying power of the air in the shaft were investigated on a number of occasions (to be referred to later on), and the values closely resembled those mentioned. The in and out currents of air were well marked, the neutral point being, on an average, 5 ft. from the bottom of the section in the winter observations, and 5½ ft. in the summer observations.

It will be seen that in winter time the temperature of the air in the shop (at head level on the workers' benches) averaged 76·0°, though the air outside was only 45·7°; *i.e.*, a difference of 30·3°. Other winter observations usually showed a temperature over 70°, so there can be no doubt that the shop was overheated. And yet we have seen that the leakage area from the stove was only a fifth to a ninth as great as that from dobbin stoves. The chief heating of the shop must have been due to the fact that there were usually seven or more of the sections drawn out fully into the shop. These sections were loaded with moulds of dried ware, which were at a temperature of about 100° when

To face p 48.

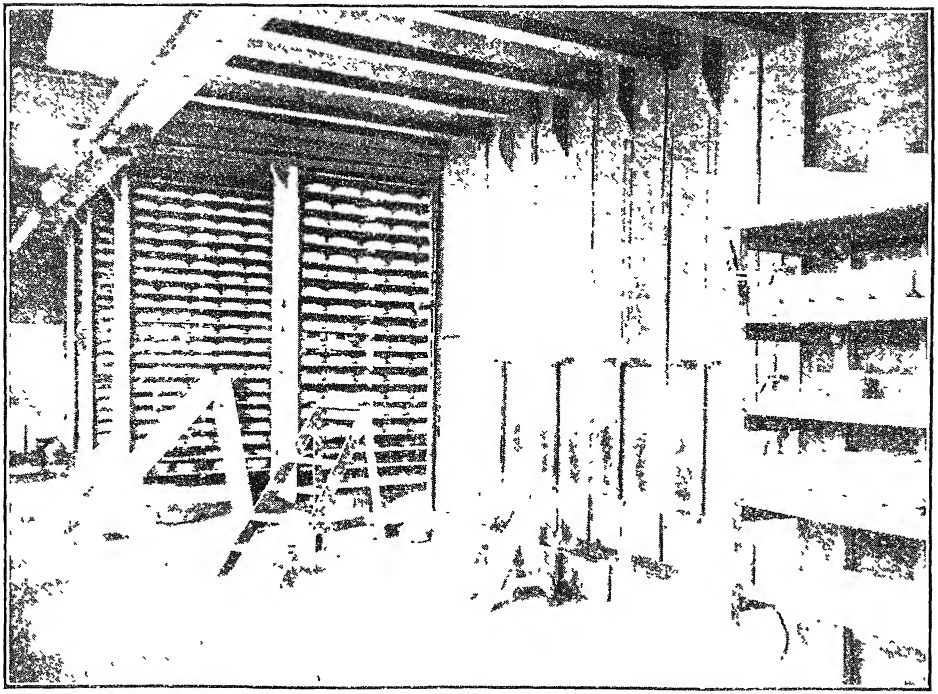

PLATE II.—Draw-out Stove at Works E, showing three sections completely drawn and one half-drawn

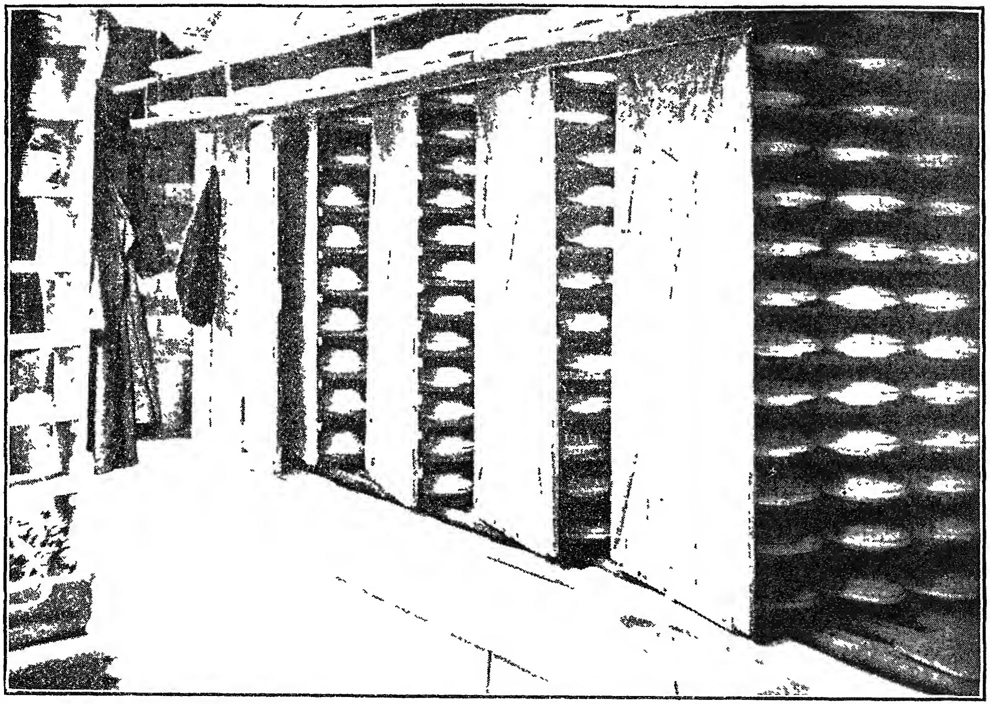

Plate III —Leaf Stove at Works D, showing four leaves and the bed of steam pipes If these leaves are moved laterally to the right, their front boards come into contact, and the gap on the left can be closed by means of the door (shown in the picture).

first drawn out, and they must have given off a tremendous amount of heat. In the summer, I attempted to estimate the times for which the various sections were drawn out and exposed to the shop. The stove had been increased in size since the winter observations, and there were altogether 28 sections, which were used by eight potters. The number of sections exposed was usually 9, and sometimes as many as 11, and even in the dinner hour 6 or 7 of the sections were left out. Between the hours of 9.30 a.m. and 4.30 p.m. on one day I went round at 10-minute intervals and noted which of the sections were exposed, and I found that roughly half of all the sections were exposed for 1 to 1½ hours, and a third of them for 2 to 3 hours. The remaining sixth were exposed for only half an hour. In the times mentioned, the moulds and ware on the sections must have given off most of their heat to the shop, and it follows, therefore that even if the leakage of hot air from the stove had been entirely stopped, the shop would have tended to get overheated. However, this was partly at the desire of the potters themselves, for they were very chary about opening the excellently designed double hopper windows with which the shop was provided. When the outdoor temperature ranged from 40° to 50° only 5 of the 82 hoppers were kept open, though the shop temperature averaged 73·2°. In summer time, when the shop temperature was at 76°, 42 of the hoppers were open, and when it was at 83°, 50 were open. Yet the hoppers were so designed that they caused no draught, even if all 82 of them had been kept open. It should be stated that the shop was a very fine one, about 33 ft. broad, 120 ft. long and 11½ ft. in height, and it could have yielded excellent temperature conditions if the potters had desired them.

At works D there were four leaf stoves, all of them embodying a feature which was met with occasionally in the chamber stoves and dobbin stoves referred to, though it was not specially commented on. This feature consists of a high pitched roof above the top of the stove which forms a roomy space into which the hot air from the stoves can rise. At the apex of the roof are one or more large ventilators, through which this air can pass to the outside. Such a system might be expected to prevent most of the back draught from the stoves into the shops, but this did not prove to be the case. The largest stove at works D contained 26 leaves, 13 each side. The leaves were 7½ ft. high, 4½ ft. deep, and 2 ft. wide. They were suspended on wheels at the top, and they could be moved laterally so as to leave a gap between any pair of leaves desired. There were usually two 1½ ft. gaps in the stove on each side. Above the leaves there was a high pitched roof which included, not only the space immediately above the tops of the leaves, but extra space from the sides of the shop as well. At the apex of the roof, about 18 ft. above the top of the leaves, there were three large louvre ventilators, one about 4 by 3 ft., and two others 4½ by 2½ ft. Hence the total

ventilator surface came to about 35 sq. ft., though the flaps were never kept more than half open, in my experience.

Many smoke tests were made in the four gaps of the stove, and during the winter observations it was found that as a rule hot air was pouring out into the shop from the upper part of two or three of the gaps, whilst the fourth gap showed an in draught right up to the top. The position of the gaps was constantly varying to some extent, and a passage door in the shop was sometimes open and sometimes shut, so the results of the observations were very irregular. As a mean of the observations made in the morning and afternoon of three days, the neutral point was found to be 16 in. below the top of the gaps, and 5 ft. 8 in. above the level of the entrance. In the summer observations, an inward current of air was observed right up to the top of two of the gaps, whilst there was an outward current only through the upper 5 to 8 in. of the other two gaps. The velocity of the inflowing air current was three or four times greater than that of the outflowing current, as can be gathered from the data in Table XII. Hence it follows that by far the larger portion of the hot air rising from the bed of steam pipes on the floor of the stove passed out through the ventilators, and not into the shop. In spite of this, the air in the shop was overheated, both in summer and winter. This is indicated by the figures in the Table, which are the means of two or more sets of observations.

TABLE XII.

Leaf Stove at Works D.

Time of Year	Level at which air was tested.	Dry Bulb.	Wet Bulb	Per cent saturation	Drying power.	Grms of water per m³.	Velocity of air Current.
		°	°				ft.
December	10 in. above entrance ..	69·1	59·1	53	10 0	9 5	97
	5 ft. above entrance (N P) ..	76 1	62 8	45	13·3	10·1	41
	6 ft. 4 in above entrance .	84 4	66 7	37	17·7	10 7	31
	Air in shop .. .	72 1	60 6	50	11·5	9·9	22
	Air outside	48 0	46 0	86	2 0	7·6	260
July ..	14 in. above entrance . ..	78 0	65 0	47	13·0	11·2	85
	6 ft 7 in above entrance	84 5	70 9	47	13·6	13·7	—
	Air in shop	79 5	65 4	44	14 1	11·0	26
	Air outside	66 0	56 0	52	10 0	8·5	100

In the three other leaf stoves at works D the leaves, five to seven in number, were fixed by hinges at the back, and the exposed gap in front could be closed by doors when desired (*cf.* Plate III.). Each of the stoves had a very high pitched roof above it, with a ventilating shaft at the apex. These shafts were of 2 or 3 sq. ft. in sectional area, and were about 10 ft. in height, but they did not prevent a large outflow of hot air into the shops. Observations made in winter time on the neutral points showed the spaces

through which cool air was flowing in, and hot air was flowing out, to be the following :—

	Inflowing Air	Outflowing Air
Stove 1	3 ft 7 in 2 ft. 11 in.	2 ft 9 in. 3 ft. 5 in.
,, 2	3 ft 3 in	2 ft. 1 in.
,, 3	4 ft 0 in 3 ft 4 in.	1 ft 4 in. 2 ft 0 in.
Mean	3 ft 5 in	2 ft. 4 in.

On an average, cool air was flowing in through half as much space again as it was flowing out, and it was flowing in at a somewhat greater velocity; *e g.*, in stove (3) the velocity of the inward air current at a point 1 ft. above entrance level was 55 ft. per min , whilst that of the outward current, 6 in. below the top of the entrance, was 42 ft. The shops had a temperature of 70° to 71° when the outside temperature averaged 48°. In the summer observations the neutral point of the air currents was 8 in. higher than in winter, and the velocity with which the hot air emerged through the upper part of the stove doors into the shops was only two-thirds as great. Hence the volume of back draught air was considerably smaller.

There can be no doubt that these leaf stoves were well ventilated, yet large volumes of hot air continually emerged into the shops This must have been due to the comparatively small suction which the ventilators exerted on the hot air, in spite of the 10 ft. shafts. The hot air rising from the steam pipes on the floor of the stoves took the line of least resistance, and it was easier for part of it to pass out laterally into the shops and part to pass vertically into the ventilators above, than for the whole of it to pass vertically.

Cabinet and Mangle-type Stoves.

These types of stove were investigated at four pottery works. At works J, where small china fancy articles were being made, there were stoves on the ground floor and the first floor, connected to one another by a ventilating shaft $3\frac{1}{2}$ by $1\frac{1}{2}$ ft. in size. Each stove was 18 by $5\frac{1}{2}$ ft. in internal area, and 9 ft. in height, and might be regarded as composed of 16 compartments, each with its sliding panel door (*cf.* Plate IV.). There were no partitions between the adjacent compartments, with the exception of some steam pipes in the ground floor stove. At the bottom of each stove were flap doors which were usually kept shut, though they could be raised for cleaning purposes. They did not fit closely and there was a gap of about an inch between the floor and the bottom of the flap, and in some instances a gap at the ends. In each compartment were three shelves, on which the moulds were placed, singly or in piles. Every 24 hours they were taken out,

generally about six at a time, and were used for three or four successive casts, after which they were returned. Consequently there was a frequent lowering of the panels of the stove compartments, but such lowerings were temporary and brief, and as the result of a large number of observations, made both in summer and winter, I found that in the first floor stove, on an average, between one and two out of the 16 panels were open, top and bottom panels being equally affected. In the ground floor stove there were two top and two bottom panels open, on an average.

Smoke tests showed that as a rule in both stoves there was an inflow of air through any lower panels which happened to be open, and an outflow of air through any upper panels. Smoke paper held at any part of the upper halves of the end compartments of the stoves indicated an outward flow of hot air, but in the middle compartments the suction of the ventilating shaft showed itself. The shaft from the first floor stove was about 11 ft. in height, and had a louvre opening above the roof. It was $3\frac{1}{2} \times 1\frac{1}{2}$ ft. in area, and anemometer readings showed that the hot air was ascending it with a velocity averaging 220 ft. per min. It drew hot air from the ground floor stove as well as that on the first floor, as there was a central opening between them. This was $3\frac{1}{4} \times 1\frac{1}{4}$ ft. in area, but as a rule only part of it was uncovered. Between the times at which the winter and the summer observations were made, two additional ventilating shafts, each 8×15 in. in section, were erected at the ends of the stoves. They drew hot air from the stoves on both floors, and the velocity of its flow was found to average 270 ft. per min. Hence the total volume of hot air extracted from the two stoves came to about 1,600 cubic ft. per min.

TABLE XIII.

Cabinet Stoves at Works J.

Place at which Air was tested.	Winter Observations.					Summer Observations				
	Dry Bulb.	Wet Bulb.	Per cent Saturation.	Drying Power	Grms of Water per m^3	Dry Bulb	Wet Bulb	Per cent. Saturation	Drying Power.	Grms. of Water per m^3.
	°	°				°	°			
Ground Floor Stove—										
In shop	53·6	49·1	72	4 5	7 7	73 0	64 8	61	8 2	12 4
Bottom shelf	61·6	54 8	63	6 8	8 8	104 3	78 1	26	26 2	13·4
Top shelf	70 5	59 8	51	10 7	9 6	106 4	79 0	26	27 4	14 2
First Floor Stove—										
In shop	56 2	51·1	70	5 1	8 2	73 6	65 5	62	8·1	12 8
Bottom shelf	97·4	72 0	26	25 4	11·0	122 3	81 8	15	40 5	12 5
Top Shelf	92 1	70 5	31	21 6	11 3	114 8	80 7	20	34 1	13 7
Air Outside	38 7	36 5	79	2·2	4 9	70 0	63 5	67	6 5	12 4

In Table XIII are recorded the means of six sets of winter observations, made on the morning and afternoon of three days, and of three sets of summer observations. It will be seen that in winter the ground floor stove did not reach at all a high temperature, but in summer it averaged 104° to 106°, and the air

had a drying power of 26 or 27. The reason of this great improvement was the installation of a horizontal bed of steam pipes on the floor of the stove, in addition to the vertical system of pipes already present. The first floor stove had the same horizontal bed of pipes both in winter and summer, and this was so efficient as to give the air a drying power of 22 to 25 in the winter, and raise it to the unprecedented value of 34 to 40 in the summer. The greater drying power of the first floor stove than that on the ground floor was due partly to the fact that the air coming to it through the central opening between the stoves was already well warmed, whilst that passing into the ground floor stove was the comparatively unheated shop air.

Temperature observations were made on the top shelf of the upper compartment and the bottom shelf of the lower compartment of each stove, and it will be seen, in Table XIII, that in the first floor stove the temperature on the top shelf was several degrees lower than on the bottom shelf, whilst the air carried more moisture. This is what one would expect, as the damp moulds deposited on the shelves would be taking heat from the stove air, and giving up moisture to it. In the ground floor stove, however, the temperature on the top shelf was greater than that of the bottom shelf. This reversal of temperature gradient was due to the vertical system of steam pipes in this stove.

It will be seen in the Table that during the winter observations the shop temperature averaged only 54° in the ground floor shop, and 56° in the first floor shop. This was distinctly too cool for comfort, and it was evident that the shop did not get sufficient heat from the stove, owing to the prevention of more than a small amount of back draught by the strong suction of the ventilating shaft. The best remedy would have been to provide the shops with an independent system of heating, but, failing this, it would have been possible to increase the back draught by blocking up the ventilating shaft to some extent. Thereby some of the hot air, which, as already mentioned, amounted in summer time to 1,600 cubic ft. per min., would have been diverted into the shops. The effect of blocking the opening between the two stoves was put to a practical test, and it was found that on the two successive days for which it was closed completely the average temperature of the ground floor stove was 6·8° higher than on the preceding day, when it was open, whilst the average shop temperature was 5·8° higher. It is true that the outdoor temperature was 3·7° higher on the two days, but if this rise be allowed for, there was still an excess of temperature amounting to 3·1° in the stove and 2·1° in the shop, which was probably due to the stoppage of the ventilation. Still, it would be necessary to repeat the experiment a number of times before thoroughly reliable figures would be obtained. There can be little doubt that even the partial closure of the shaft from the

first floor stove would have produced a considerable effect on the shop temperature.

The excellence of the heat-retaining powers of the stoves is proved by the summer observations, for the shop temperature was found to be only 3 or 4° higher than that of the outside air, in spite of the stoves being heated to 104°–122°.

The newly erected cabinet stove at works K is similar to those at works J, except that the ventilation is much poorer. The stove is 24 × 6 ft. in area, and 9 ft. in height, but there are only two small ventilating shafts, 8 and 10 in. in diameter. The cabinet stove at works F had an even poorer ventilation, as its single ventilating shaft was only 7 in. square, and it opened into a small loft above, and not to the air outside The stove was 19 × 4 ft. in area, and was used for drying earthenware toilet services. The lower panels were usually kept open, but the upper panels were mostly shut. The heat in the steam pipes was moderate, and in the winter observations the outflowing air at the top of the stove had a temperature only 9° above that of the air flowing in at the bottom, but in the summer observations the difference amounted to 18°, and the drying power of the outflowing air was 23. The temperature of the shop averaged 67° in winter, when the outside temperature was at 45°, whilst in summer the temperatures observed inside and outside were 72·2° and 63·8°.

The cabinet stoves described all suffered from the defect that they allowed a flood of hot air to pass back into the shop whenever the upper door panels were opened for the purpose of introducing or removing moulds and ware. It is probable that this theoretical defect was not as a rule of great practical importance at the works described, but it might have been if the panels had been opened more frequently. In one instance alone of all the stoves investigated by me did the design conform —except in one minor respect—to theoretical requirements. This was the newly erected mangle-type stoves at works L, of which there are three double stoves, and one single one. The double stoves are about 7 ft. wide, 7½ ft. from back to back, 16 ft. high at the sides, and 19 ft. high in the middle (*cf.* Plate V.). They reach from floor to roof of the shops, and hot air escapes by two narrow gaps between the tiles near the apex of the roof. There are two systems of shelves in each stove, suspended by steel rods from chains, which move over cog-wheels revolving near the top and bottom of the stoves. The shelves are moved on by means of a worm gear outside the stove, and owing to mechanical devices they move easily, without any jerks. About 3½ ft. above floor level there is a flap on each side of the stove, which can be turned back to a horizontal position. Thereby access is obtained to the shelves, but no hot air escapes even if the flaps are left continuously open, as there is a weak inflowing draught of air through the gaps. The stoves are heated by a system of pipes running vertically, from floor to roof, between the two systems of revolving

To face p. 54.

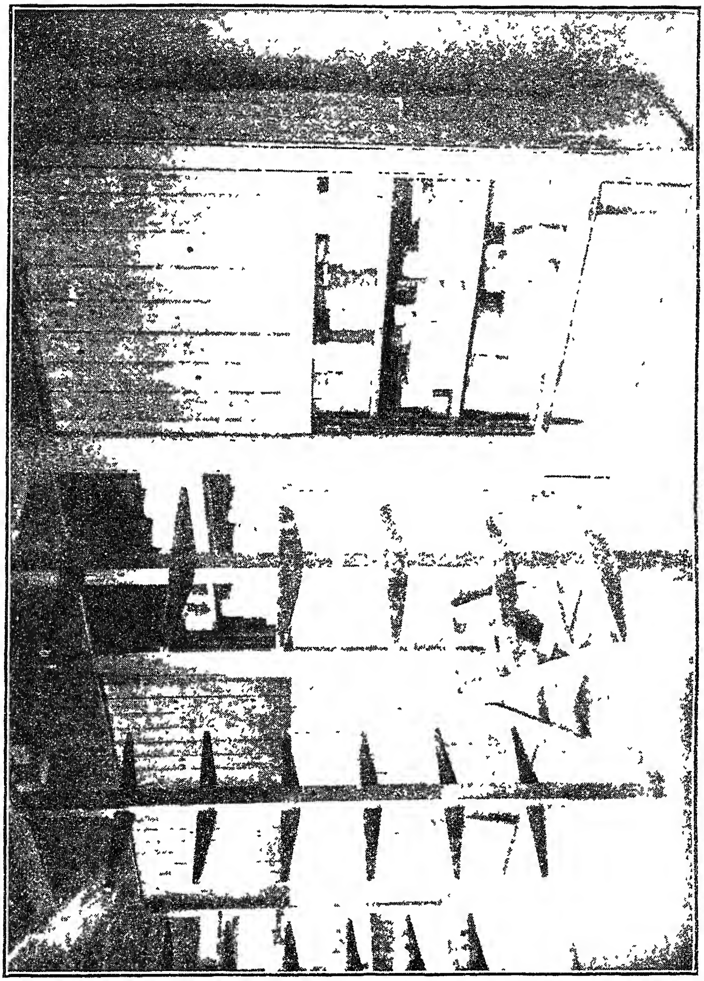

Plate IV.—Cabinet Stove at Works J, showing one top and one bottom panel open.

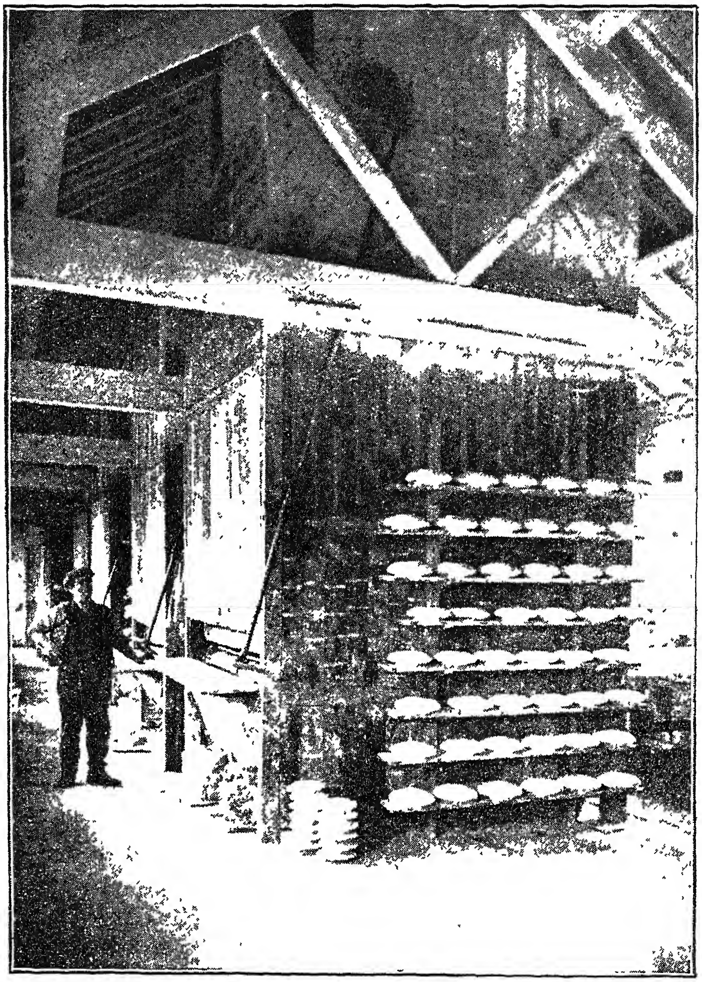

Plate V —Mangle-type Stove at Works L. (Patent applied for No 1147/1921)

Note the worm gear for moving on the shelves of ware.

shelves. It was impossible to obtain access to the interior of the stoves at the very top, but by means of a small door I was able to sample the temperature at a spot 3 ft. below the top, and midway between the hanging shelves of one of the two systems. The following results were obtained :—

	Dry Bulb	Wet Bulb	Per cent Satura-tion	Drying Power	Grams of Water per cubic metre.
	°	°			
Air near Top of Stove	88·5	74·1	45	14·4	14·8
Air entering through Flap opening	75·3	63·3	49	12·0	10 7
Air Outside	69·4	57·3	47	12·1	8·5

It will be seen that the air did not possess a great drying power, but it extracted a good deal more moisture from the drying ware than was observed to be extracted in the great majority of other stoves (*see* previous Tables of data). Presumably this was due to the slow circulation of air through the stove, but if, in practice, it were found to be too slow, it could be easily increased by widening the ventilation gaps in the roof. This lack of capacity to vary the ventilation was, in fact, the one small defect I noticed in the design.

It will be realised that the moulds of ware, when first placed on the shelves, were exposed to comparatively cool air, but as they ascended the stove they were heated more and more, till they met the hottest air when they reached the top. On their downward course they gradually transferred their heat to the ascending shelves of ware, and by the time they were withdrawn from the stove they had very little surplus heat left. That is to say, practically none of the heat from the steam pipes had a chance of reaching the shop, either directly or indirectly, except through the walls of the stoves. If these were made heat proof, it would be essential to instal an independent system of heating in the shop, but at works L this had not been found necessary, so sufficient heat must have leaked through the stove walls. The shop was very much cooler than it had been previous to the installation of the mangle-type stoves, and the chamber stoves, which they replaced, were less convenient in other ways. The mould runners had to make much longer journeys, for with the new stoves they now need to move only about 3 ft., between worker's bench and stove shelves. In fact, one of the mould runners was dispensed with as unnecessary.

The stoves in question were used for drying china saucers and plates, but the manager is intending to erect similar stoves for china cups. It should be stated that the shelves of the stoves were not solid boards, but consisted of two $2\frac{1}{2}$-in. wooden strips, with a 2-in. gap in between.

The Influence of Air Velocity on Drying Power.

In the observations above described the drying power of the air in the stoves was recorded, in so far as it was dependent on the temperature and humidity of the air. Nothing was said about the effects of ventilation, though this is usually considered a very important factor. Of the many pottery managers whom I consulted, none ventured to speak with any definiteness as to the relative parts played by heat and by ventilation in the drying of the ware. The potters themselves, arguing from practical experience, were generally of the opinion that heat was the one requirement necessary, and that ventilation did not much matter. As their opinion is not founded on exact evidence it may be erroneous, so it is important to test it by accurate methods.

Theoretical evidence bearing on the question is obtainable from the science of meteorology. Moist clay ware, in process of drying, is comparable to a water surface exposed to air, and the rate of evaporation of water at various temperatures and wind velocities is important to meteorologists. The determination of the wind effect is very difficult, and the observations of various investigators are contradictory. De Heen and Schierbeck, Svenson and Travert* all find that the rate of evaporation varies with the square root of the wind velocity, but Bigelow (1910), in his more recent investigations confirms Dalton's view, enunciated in 1803, that it varies directly with the wind velocity. Bigelow determined the rate at which water evaporated from pans 2 to 6 ft. in diameter, in wind of known velocities (measured by anemometer). He found that if the rate of evaporation in calm air be taken as 1·00, it increased to 1·07 in a wind of 1 kilometre per hour (54·7 ft. per min.), to 1·14 in a wind of 2 kilometres, to 1·21 in a wind of 3 kilometres and so on. His estimate of the wind effect is considerably greater than that of other investigators, but even then it is a small one at such velocities of air current as are found in drying stoves. In the data previously recorded these velocities scarcely ever exceeded 100 ft. per min. It might be thought that Bigelow's results contradict common experience, *e.g.*, as to the effect of a breeze on the rapidity with which washing dries when hung on a line. There is no real contradiction, however, for a gentle breeze, on the Beaufort scale, has a velocity of 6 to 10 miles per hour. This corresponds to a 68 to 113 per cent increase in the rate of drying, on Bigelow's figures.

In comparison with this small effect of air velocity on the rapidity of drying, that of temperature is tremendous. As already stated, the drying rate at a given temperature depends on the difference between the maximum tension of aqueous vapour at the temperature in question, and the tension of aqueous vapour present in the air. For instance, at 60° F. the tension of aqueous vapour is 13·2 mm., and if the air were 70 per cent.

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* For references *see* Hann (1915).

saturated with moisture (this being about the average value observed in potters' shops at the temperature mentioned), it follows that the drying rate of the air would be represented by the figure 13·2—9·2=4·0. Supposing this air at 60° passed into a potter's stove and got heated up to 70°, its drying power would be 18·6—9·2=9·4, or 2·4 times greater than before. If it were heated to 80° its drying power would become 4·3 times greater; if to 90°, 6·7 times greater, and if to 100°, no less than 10·0 times greater. Arguing from these data, there would seem to be no question that the potters are right in thinking that heat is the one thing necessary, and that ventilation does not much matter. Let us suppose that a fixed amount of heat is available from the steam pipes of a stove, and that this heat can be utilised to warm either 1 volume of air from 60° to 100°, 2 volumes of air from 60° to 80°, or 4 volumes of air from 60° to 70°. Supposing the 1 volume of air, when passing over the moist ware, moved at a velocity of 10 ft. per min., it would, on Bigelow's figures, have its drying power of 10·0 increased only by 1·3 per cent., so its total drying power would be 10·13. The 2 volumes of air would move at a velocity of 20 ft., and in consequence the drying power would be raised from 4·3 to 4·41, whilst the 4 volumes of air would move at a velocity of 40 ft., and the drying power would be increased by 5·1 per cent.; but this would only mean a rise from 2·4 to 2·52. Thus:

Temperature of Air passing through Stove.	Velocity of Air Current in feet per min	Drying Power due to Air Current	Drying Power due to Temperature	Total Drying Power
100°	10	1 013	10·0	10·13
80°	20	1·026	4·3	4 41
70°	40	1·051	2·4	2 52

Experimental Evidence.

It might be argued that the evaporation of moisture from a water surface and the drying of clay ware in a stove are so little comparable that no conclusions can be drawn from the one condition to the other. Though I do not agree with this view, it would obviously be more satisfactory to investigate the rate of drying of the ware under known conditions of temperature and air velocity. To carry out such experiments on an adequate scale, it would be necessary to have means for accurately controlling air currents and temperatures. Such means are not available in ordinary potters' shops. They require an experimental laboratory. However, it was thought to be worth while to make a certain number of preliminary experiments with such facilities as were available, for even these experiments are quite sufficient to indicate the comparatively small effect of air currents.

The first series of experiments was made with a saucer mould 7 in. in diameter and weighing 24 oz. (680 grm.). A deep groove was cut in the mould from the edge to the centre, and a thermometer (of the usual laboratory type) was laid in it, so that its bulb came almost exactly in the centre of the mould. It was covered over with a thin layer of plaster of Paris, a twentieth of an inch in thickness, and the surface of this layer was flush with the surface of the rest of the mould. A layer of clay, of the usual thickness and consistency, was put on the surface of the mould, and smoothed down by hand, for the thermometer would have prevented the employment of a jolly. The mould was placed on a solid wooden shelf in a chamber of which the temperature was kept at approximately 80°, and the temperature of the thermometer was read at 5 or 10 minute intervals. From the lower curve on the right of Fig. 1 it will be seen that the temperature of the mould rose from 55° to 65° in the first half hour, and then the rate of warming got much slower, but from 1½ hours till 6 hours after the start the temperature rose at a practically constant rate. This steady rise was due to the operation of two conflicting factors. The rate of warming of a dry mould would be strictly proportional to the difference of its temperature from that of the air surrounding it ; *e.g.*, if the air were at 80° the mould would take the same time to warm up from 70° to 71° as from 60° to 62°, or 50° to 53°. Supposing the mould with its clay ware had warmed up throughout its period at the same proportional rate that it warmed up in the first five minutes, its rise of temperature would be that indicated by the dotted line curve shown in the Figure. Owing to the evaporation of moisture from the moist clay, the rate of warming was greatly retarded, but the relative rate of retardation got less and less as the clay ware got drier and drier, and so, by a mere chance, the actual rate of warming up kept nearly steady for four hours.

In another experiment the same mould, with freshly prepared clay ware, was allowed to rest on two two-inch strips of wood, with a two-inch gap between them. In that the hot air could now get to the whole of the under side of the mould as well as to the upper side, it warmed up considerably faster. Its warming curve—in air at 79°—is shown on the left of Fig. 1, and it will be seen that at one period its temperature scarcely rose at all. This must have been due to the cooling effect of the rapidly evaporating moisture. The theoretical rate of warming is shown as a dotted line curve.

Warming experiments were made at other air temperatures, and they confirmed the results quoted, but they showed that unless the chamber was kept at the same temperature, both dry and wet bulb, in all experiments, it would be impossible to get consistent results when the velocity of the air current was varied. Hence I did not seriously attempt them. The two experiments recorded were made in still air, with no artificial ventilation.

The slowness with which the mould and moist ware takes up the temperature of the surrounding air is rather remarkable, especially when the small size of the mould is considered. The rate of warming of moulds of similar shape varies as the cube root of weight of the mould, so the mould of an 8-in. plate (to be referred to later), which weighed 1,550 grm., would have taken 32 per cent. longer time to warm up than the mould used in these experiments.

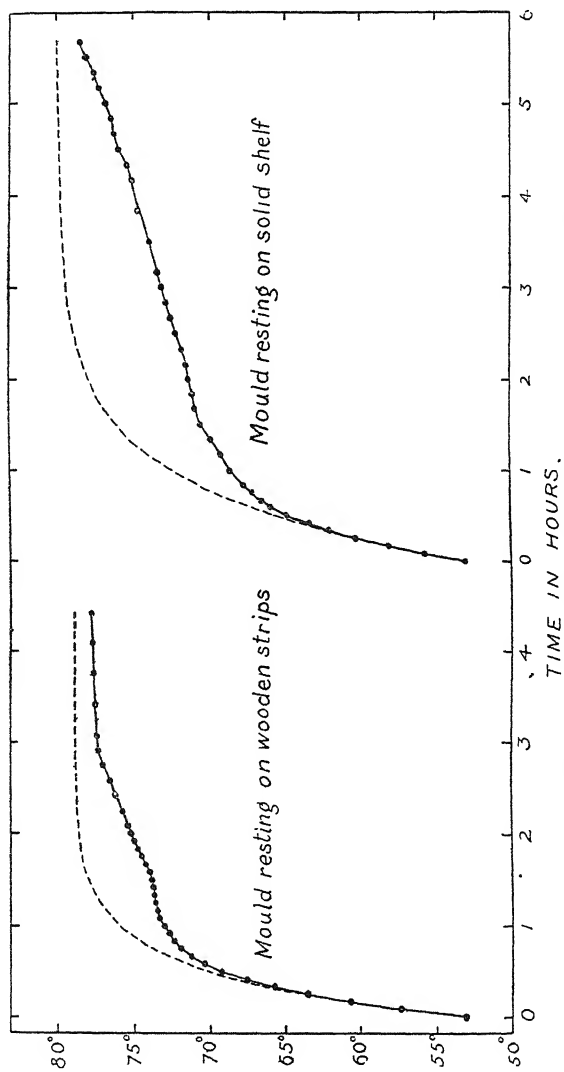

Fig. 1. Rate of warming of mould and fresh clay ware in still air at 79°—80°.

A much simpler and more accurate method of investigation is to determine the rate of *cooling* of a hot mould and ware, when placed in cold air. This rate of cooling, just like that of warming, is proportional to the difference between the temperatures of the mould and of the air, and it is quite easy to keep the temperature of

the air constant, whatever its velocity of movement. A series of experiments was first made with the mould and clay ware after it had been thoroughly dried. It was heated to about 110°F., and then placed on a wooden shelf in a room at a temperature of about 46°. Various air velocities were induced by means of an electric fan, which was placed 2 to 8 ft. off, in such a position as to drive an air current horizontally over the mould. The actual velocity was determined by making three or four kata thermometer readings during the cooling, and it was found to remain very steady. The room temperature was likewise very steady, and did not vary more than 0·2° during an experiment.

The number of degrees through which the mould cooled in successive 10-minute intervals was determined, and each number was divided by the difference between the average temperature of the mould and the air temperature. The cooling rate thereby ascertained might be expected to be constant, but in practice it was found that both at high temperatures and at low temperatures the mould cooled rather slower than at intermediate temperatures. This intermediate period, therefore, was taken to represent the true rate of cooling, and the cooling rates obtained are recorded in Table XIV. When the fan was not turned on at all, the mould cooled steadily from 90·4° to 62·8°, five 10 minute periods being required. The average cooling rate came

TABLE XIV.

Influence of Air Current on Cooling Rate of Mould and Dry Ware.

Air Temperature.		Temperature Range of Cooling recorded.	Rate of Cooling during Successive 10 min. Intervals	Mean Rate of Cooling	Per cent increase in Rate of Cooling	Air Velocity in ft per min
Dry Bulb	Wet Bulb					
°						
45·2	—	90·4—62·8=27·6°	0·19, 0·19, 0 19 0·18, 0 18	0·186	0	11 ft.
45·1	—	88·7—58·1=30·6°	0·23, 0·24, 0·25, 0·25, 0·24	0·242	30	106 ft.
47·3	—	87·0—56·4=30·6°	0·29, 0·30, 0·30, 0·30, 0 29	0·296	59	294 ft.
47·2	—	76·0—51·8=24 2°	0·36, 0·36, 0·38, 0·36, 0·36	0 362	95	585 ft.

Cooling of Mould and Moist Ware.

46·7	44·6	85·3—52·1=33·2°	0·24, 0·25, 0·25, 0 24, 0·24, 0·24, 0·24	0·243	0	12 ft.
45·0	41·7	89·3—48·5=40·8°	0·31 0 32 0 33 0 33, 0·33, 0 31	0 322	32	49 ft
49·5	46 5	86·9—50·7=36·2°	0·45, 0·44, 0·44, 0·45, 0·44	0 444	83	194 ft.
46·4	41·9	86·4—46·9=39·5°	0·55, 0·54, 0 52, 0·53	0·535	120	635 ft.

to 0·186, whilst the kata thermometer showed a mean air velocity of 11 ft. per min. With the fan revolving so as to produce an air velocity of 106 ft. per min., the rate of cooling was increased 30 per cent., and one may therefore assume that the rate of warming of dry clay ware in a hot chamber would be augmented to a similar extent by a similar air current. With air currents of greater velocity the rate of cooling showed smaller increments, as can be gathered from the lower curve in Fig. 2, and it would have taken an air current of 630 ft. per min. to make the mould cool twice as fast as it cooled in calm air.

The observations were repeated on the mould covered with freshly prepared clay ware. It was heated up quickly, about 20 minutes being required, and by means of weighing the mould and ware (*a*) when freshly prepared, (*b*) when heated up, (*c*) at the end of the cooling observations, and (*d*) after a subsequent thorough drying, it was found that the ware lost less than a tenth of its total moisture during the preliminary heating, and only a fifth during both heating and subsequent cooling. It was therefore in a thoroughly moist state throughout the cooling observations. The results of these observations are recorded in the lower half of Table XIV. It should be remembered that the effective air temperature was now the *wet* bulb temperature, and not the dry bulb temperature, as before. In calm air the mould and moist ware cooled 31 per cent. faster than the mould and dry ware, owing to the effect of the evaporating moisture. The influence of air current on the cooling rate was considerably greater at low velocities, for a 49 ft. current caused rather more

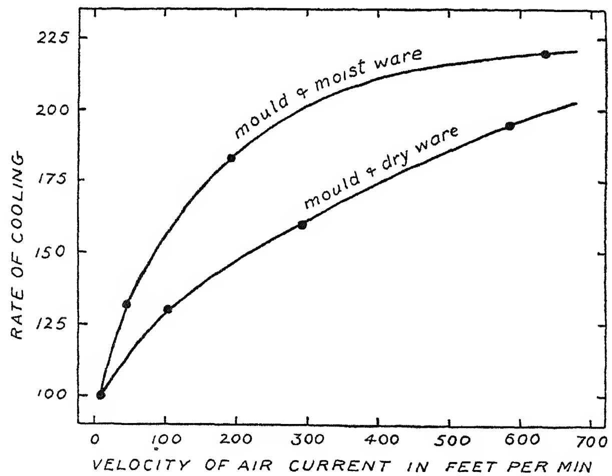

Fig 2. Effect of air velocity on cooling of mould and ware

acceleration than a 106 ft. current did on the mould and dry ware. With greater velocities, however, the effect got relatively smaller and smaller, and it can be seen from Fig. 2 that if the curves were produced they would cut one another; *i.e.*, the dry ware would be relatively more affected than the moist ware.

We have seen that an air velocity of 50 to 100 ft. per min. is often met with in drying stoves, the average rate of outflow recorded in Tables I to XII for the air currents near the top of the doorways being 70 ft. In the light of the observations just described this air velocity would increase the rate of drying of the moist ware by about 40 per cent., whilst it would increase the rate with which the final traces of moisture were driven off—when the ware could be more comparable to the conditions observed in the mould and dry ware experiments—by 20 per cent No great accuracy can be claimed for these figures, for obviously it would be necessary to make much more extensive observations by more exact methods and under all sorts of conditions, before a final conclusion could be arrived at, but such as they are they show that air velocity is more important in the drying of ware than meteorological observations would lead us to imagine. At the same time it does not approach the importance of high temperature, and even the figures just quoted suggest more effect than is actually produced, for several reasons.

Firstly, it is to be remembered that all the air velocities recorded in Tables I to XII held only so long as the stove doors were open. When they were shut, which happened throughout non-working hours, and usually for half or more of working hours, the air velocities would have been much smaller. Numerous observations were made by means of the kata thermometer on the velocity of the air currents in the ground floor cabinet stove at works J, and they were found to vary from 16 to 42 ft. per min.; but four of the 16 panels were usually open during the observations. In the leaf stove at works E it was possible to calculate from the known velocities of outflow of air through leak holes and up the ventilation shaft, that the velocity with which air was passing through the stove during working hours was about 10 ft. per min.; but in non-working hours it must have been less.

Secondly, it should be remembered that the velocities recorded are maximal values which apply only to the air near the top of the stove doorways. The average velocity at the doorway is probably not two-thirds as great, whilst it must be less still inside the stoves unless there is a good-sized ventilator. Supposing the average velocity were equal to half the maximum velocity shown at the doorway, it would follow that when the stove doors were open the rate of drying of the moist ware would be increased by about 20 per cent. This value assumes that when the doors are closed, there are air currents of 12 ft. per min. inside the stoves, for it will be seen in Table XIV that the cooling rate taken as standard was made in air of this velocity. The observation recorded was made in a room with closed door and window, but the inevitable ventilation through the chimney, the floor boarding and elsewhere always produces small air currents of this order, and it is probable that a somewhat similar amount of air movement is present in stoves, even when the doors are shut.

As has already been pointed out, the rate of cooling of the mould and ware was not proportional to the actual velocity of the air current, but to some lower power of the velocity. This fact is confirmed by Hill's (1915) kata thermometer observations. The formula for the rate of cooling of the dry kata shows that the rate varies as the square root of the air velocity. Recent observations (Hill, Vernon and Hargood-Ash, 1922), with the wet kata show that its rate of cooling depends on the cube root of the air velocity. Hence it follows that, with increasing air velocities, the effect on the cooling rate of the wet kata, as compared with that on the dry kata, gets relatively smaller and smaller. This fact corresponds with the above recorded observations on moist and dry clay ware, but no close numerical comparison is possible between the rate of cooling of the clay ware and the kata thermometer. The kata thermometer, owing to its small size, is more sensitive to air currents. For instance, the cooling rate of the dry kata is doubled by increasing the air velocity from 11 ft. per min. to 187 ft., whilst we saw that an air current of 630 ft. was needed to double the rate of cooling of the mould and dry ware. However, the rate of cooling of the moist ware corresponds fairly well with that of the wet kata, for the relative kata cooling rate at air velocities of 12, 49, 194 and 635 ft. is 100, 129, 175 and 253 respectively, whilst we saw that the cooling rates of the mould and moist ware at the same velocities were 100, 132, 183 and 220. No great stress can be laid on this correspondence, for it is evident that a large mould, covered on two-thirds of its surface with moist clay, and dry on the other third, cannot be closely comparable to a small kata thermometer bulb of entirely different conformation, and covered all over with wet muslin. The various conflicting influences which control the cooling rate of the mould and of the kata must be very different, but in the present instance they happen to neutralise one another to the same extent, and thereby yield these roughly corresponding figures.

It was stated above that, according to Bigelow, the rate of evaporation of water from pans varies directly with the air velocity, and is increased only 7 per cent. for each kilometre per hour of air current. This conclusion appears, at first sight, to be in contradiction to the results obtained with the wet kata thermometer, but it is not so in reality. Bigelow never had an opportunity of determining the effects of very low air velocities, whilst it is impossible to make observations by his method at high velocities, as the surface of the water in the pans becomes broken up by the air currents. At intermediate velocities, such as he investigated, his results roughly correspond to the kata thermometer results. For instance, if the cooling rate of the wet kata at an air velocity of 3 kilometres per hour (164 ft. per min.) be taken as 100, that at 4, 5, 6 and 7 km. comes to 109, 117, 124 and 130 respectively, or it shows increments of 9, 8, 7 and 6 per cent. for each km., and these values approximate to the 7 per cent. observed by him.

Weighing Experiments.

It is evident that the question of evaporation of moisture in air currents of various velocities is an exceedingly complex one, and some doubt must rightly attach to the numerical estimate I have given of the effect of the air velocities met with in potters' stoves on the rate of drying of the ware. The most satisfactory test of all would be to make a systematic series of observations on the rate of drying under known conditions of temperature and air velocity. In order to indicate the value of such observations, I made a preliminary series under workshop conditions with the draw-out stoves at works E. These stoves had 10-in. flap doors below the sections. They fitted well, and were usually kept shut, except for cleaning purposes, but when opened they allowed a large volume of extra air to pass underneath the horizontal bed of steam pipes, and thence through the stove. The neutral point of the air currents in the 20-section stove was found, on an average, to be only $1\frac{1}{4}$ ft. from the bottom of the section (and $8\frac{3}{4}$ ft. from the top) when the flaps were open, as against $5\frac{1}{4}$ ft. from the bottom (and $4\frac{3}{4}$ ft. from the top) when the flaps were closed. The opening of the flaps not only caused hot air to emerge from the stove into the shop through a much larger leakage area than before, but it came at a greater velocity, as it averaged 159 ft. per min. in the leak holes at the top of the stove instead of 98 ft. The velocity of ascent of air in the shaft was not changed, however, and the velocity of flow of air through the stove worked out roughly at 15 ft. per min. instead of 10 ft. Observations on the rate of drying of two sizes of plates were made under these two conditions of air velocity, whilst others were made when some of the leak holes of the stove were blocked up in the manner previously described. This blocking was calculated to reduce the velocity of air passing through the stove to about 8 ft. per min.

In order to estimate the loss of moisture of the plates in the stove, it was found to be necessary to weigh a sample of the freshly made moist plates on each occasion, as well as one of the dried plates. The reason was that the profile instrument, used for smoothing down the clay on the mould, is freshly set each day by eye, and in consequence the average thickness of the moist plates varies distinctly. In extreme cases their average weight varied 9 per cent., though the variation in the sample data recorded is somewhat smaller than this. Ten weighings

TABLE XV.

Weight of 7-in. Plates Before and After Drying.

		Mean.
Heavy Sample —		
Moist	=402, 397, 396, 391, 386, 385, 382, 382, 381, 371=	387·3 grm.
Dry	=299, 296, 295, 294, 294, 293, 293, 291, 290, 288=	293·3 grm.=24·3 per cent. loss.
Light Sample.—		
Moist	=373, 371, 364, 363, 359, 358, 356, 356, 355, 350=	360·5 grm
Dry	=286, 286, 277, 277, 275, 274, 273, 273, 271, 270=	276·2 grm.=23·4 per cent. loss

were made on each occasion, as this number gave a reliable average It necessitated the weighing of the mould before and after the clay ware had been applied to it by the potter. Ten sets of weighings were made of the dried plates, but they were weighed in groups of four at a time (or three of the larger plates), so they showed a smaller range of variation, as can be gathered from the sample data quoted The consistency of the data is proved by the fact that with one small exception all the plates of the heavy sample, both moist and dry, were heavier than any of the corresponding plates of the light sample, though the percentage of moisture lost on drying was almost the same in each case. It is to be noted that the moist and dry weighings recorded do not relate to identically the same plates, but are merely chance samples of the same block of plates The weighings were made on a balance which turned to 0·2 grm. when under a load of 2,000 grm (4·4 lb.), but it was found to be unnecessary to weigh more accurately than to the nearest gram.

The plates dried in the 20-section stove were so-called 8-in. plates, though they were about 9¾ in. in diameter when moist. They weighed about 500 gm. (18 oz.) in their moist state, and they were made by the potter every morning when he first came on to work. As a rule, they were dried for 24 hours, but I obtained permission to weigh samples of them after 8 hours' drying Between 9 a m and 5 p m I frequently took the temperature of the hot air emerging from the leak holes at the top of the stove, as well as that in the ventilating shaft, and the data in Table XVI show the average results obtained Instead of recording the wet bulb temperatures, I have quoted the relative drying power (*i.e.*, difference of dry and wet bulb) It will be seen that this drying power was greatest when the air velocity in the stove was greatest, and least when it was least. This may have been a chance result, for there was no certainty that the steam supplied to the stove pipes was exactly the same each day, but more probably

TABLE XVI.

Influence of Ventilation on the Drying of 8-in. Plates.

Conditions of Ventilation	Probable velocity of air current	Dry Bulb Temperature of Air in				Relative Drying Power of Air in				Percentage loss of moisture in			
		Leak Holes	Shaft	Mean		Leak Holes	Shaft	Mean		8 hrs		24 hrs	
		°	°		°								
Leaks Partly Blocked	8 ft	91·8	90·4	91·1	98·1	20·0	22·2	21·1	25·3	9·9	11·2	18·1	19·2
		107·4	103·1	105·2		29·4	29·6	29·5		12·5		20·3	
Ordinary	10 ft	94·8	98·6	96·7	94·7	22·6	29·3	26·0	26·4	13·2	12·6	24·9	24·5
		91·6	87·5	89·6		28·4	24·2	26·3		11·7		24·2	
		100·0	95·4	97·7		27·3	26·8	27·0		12·8		24·5	
Bottom Flaps Open	15 ft	94·1	102·1	98·1	98·0	23·3	31·6	27·5	27·7	15·3	14·6	21·8	23·0
		97·0	98·8	97·9		25·7	29·9	27·8		13·9		24·2	

the reason is that when the bottom flaps were open most of the inflowing air passed between the steam pipes instead of above them, and thereby extracted more of their heat. As would naturally be expected, the plates showed the greatest loss of moisture (in 8 hours) when air velocity and drying power were

greatest, and least loss when they were least, but it is impossible to say how far each of these two variable conditions contributed to the result. After 24 hours' drying, the plates kept under ordinary conditions of ventilation showed the greatest loss of moisture, whilst those kept with partly blocked leak holes showed the least loss, but as I did not obtain any information about the temperature of the stove during the last 16 hours of the drying, it is unsafe to draw conclusions.

A somewhat similar set of observations was made with a smaller draw-out stove, which was separated from the big one by a brick partition. It had only four sections, of the same size as the others. The temperature of the air in the ventilating shaft coming from it could not be ascertained, but observations were made in the leak holes, and they corresponded roughly with those in the big stove. The plates dried in this stove were so-called 7-in. plates, and they were made regularly at 8 a.m. and 4 p.m., so the amount of moisture lost by one set of plates in 8 hours and by the other set in 16 hours was determined. The experimental results are recorded in Table XVII, and it will be seen that the mean drying power of the air was practically

TABLE XVII.

Influence of Ventilation on the Drying of 7-in. Plates.

Conditions of Ventilation.	Dry Bulb Temperature of Air		Relative Drying Power of Air		Percentage Loss of Moisture in 8 hrs.		Percentage Loss of Moisture in 16 hrs.	
	°	°						
Ordinary	92·0		21·7		17·8		26·0	
"	98·6	98·0	26·9	26·0	18·1	18·9	—	25·0
"	98·3		26·9		18·6		24·0	
" . . .	103·2		28·5		21·1		—	
Bottom Flaps, open .	98·5		26·0		19·6		24·0	
" "	99·7	99·0	26·5	26·5	19·4	19·5	23·4	23·9
" "	98·8		26·9		—		24·3	

the same under ordinary conditions and when the bottom flaps were open. It was impossible to determine what numerical difference the opening of the flaps made in the velocity of the air current in the stove, but it was probably about the same as in the big stove, for the neutral point was 2 ft. lower, and the air emerged from the leak holes at a velocity of about 90 ft. per min., instead of 30 ft. The effect on the rate of drying was small, as the ware lost only 6 per cent. more moisture in the 8-hour experiments. In the 16-hour experiments the ware lost less moisture in the rapid air current than in the slow one, but no information was available as to the temperature and drying power of the air under the two conditions.

In contrast with the small effect produced by the different air currents, there was a considerable effect produced by the differences of temperature and drying power. It will be seen that

in the four experiments made under ordinary conditions, the drying power of the air varied from 21·7 to 28·5, whilst the loss of moisture ran parallel and varied from 17·8 per cent. to 21·1 per cent.

Evidence showing the effect of temperature and drying power was obtained in another way. The sections had 18 shelves each side, on each of which were resting eight moulds Confining myself to the outer four moulds of the upper nine shelves, *i.e.*, to the contents of the outer and upper quarter of the section, I weighed the 8-in. plates on them in various combinations so as to determine the extent of their drying. In one series I compared the weights of the 12 plates on the upper, middle and lower sets of three shelves, and found that they showed considerable differences in their loss of moisture. As can be calculated from the data in Table XVIII, the lower set lost 18 per cent. less moisture than the upper set during their 8-hour drying period. On three occasions the section was pulled out a few inches from its frame, and the temperature of the air emerging at the level of the 2nd, 5th, and 8th shelves was determined (*i.e.*, at the mid point of the three sets of shelves). The average data quoted in the Table show that the drying power of the air ranged from 25·1 for the upper shelves to 17·0 for the lower, but it is to be remembered that this considerable difference did not necessarily hold when the section was completely pushed home. It is probable that, in such a case, there would be more equalisation of temperature. In any case, it is obvious that the rate of drying was greatly affected by the drying power of the air.

TABLE XVIII.

Dependence of Drying Rate on Temperature.

Position of Plates.	Percentage Loss of Moisture			Mean Temperature		Drying Power of Air
	1st day	2nd day	Mean	Dry Bulb	Wet Bulb	
				°	°	
Upper three shelves	13·8	12 0	12·9	99 8	74 7	25 1
Middle ,, ,,	13 2	9 3	11 3	96 6	74 2	22·2
Lower ,, ,,	12·7	8 5	10 6	90 4	73 4	17 0

Another series of observations might be held to suggest the importance of air velocity in drying. The moulds rested, not on solid wooden shelves, but on two strips of wood, each 2½ in. wide, with a 2¼-in. space in between. This enabled the hot air to get at the moulds underneath, and it distinctly accelerated the rate of drying To determine the numerical effect, the middle pair of the four moulds on each shelf were placed on four thicknesses of brown paper, which blocked up the gap between the strips of wood. After 8 hours' drying the

average loss of moisture of the plates on the moulds was found to be 14 per cent. less than the average loss shown by the outer and inner sets of plates.

	Percentage of Moisture Lost on		
	1st day	2nd day	Mean.
Outer and Inner Sets of Plates (unprotected)	13·2	11 8	12·5
Two Middle Sets of Plates (protected) ..	12 2	9 4	10·8

This result confirms the observation, described in a previous section, in which a mould with its moist clay ware was found to warm up considerably faster when placed on wooden strips instead of on a solid shelf Again, when the mould with its dry clay ware was allowed to cool in still air, it was found that the rate of cooling was 32 per cent quicker when the mould rested on the wooden strips. These observations show that mere exposure of the under surface of the mould to hot or cold air, as the case might be, greatly accelerated the rate at which it warmed or cooled, quite apart from any question of air velocity. Whether air velocity has a relatively greater effect on the rate of drying when the under surface of the mould is exposed than when it is unexposed, can be determined only by systematic experiment. It is astonishing that one so seldom meets with drying shelves made of wooden strips and an air gap between. In my own experience not more than about 10 per cent. were of this form. All the rest were of solid wood, though it is self-evident that they must reduce the rate of drying.

In a third series of observations I determined the rate of drying of each of the four vertical sets of 9 plates, passing from the outer edge of the leaf towards the middle. There was not much difference, the loss of moisture amounting to 8·7, 9·8, 9·8, and 10·4 per cent. respectively in eight hours.

Practical Conclusions.

Though the evidence relating to the influence of air velocity on drying is somewhat meagre, it is sufficient to indicate that working potters are right in their contention that, for the drying of moderate-sized articles and of moulds, high temperature is the important requisite. It is obvious that a certain amount of ventilation is essential ; but so far as the drying of the ware was concerned, most of the stoves investigated had sufficient leak holes to ensure a fair ventilation even if they had had no structural ventilators whatever. The Interim Report of the National Council of the Pottery Industry on Potters' Drying Stoves (1920), states that in unventilated or under-ventilated stoves "a great deal of air saturated with moisture collects in the stoves themselves and impedes drying" ; but I have met with no evidence to substantiate this view. The data in Tables I to XIII show that

in no single instance was the hot air emerging from stove to shop so highly saturated with moisture as the cooler air flowing in from shop to stove. In Table XIX I have averaged the data relating to back draught air, according as it came from stoves where the ventilation was spoken of as good, or bad. That of the dobbin stoves at works B was counted as "bad," in that the fan was not on; so was that of the chamber stove at works G (in winter), as the ventilators were kept closed. In the case of the chamber stoves at works K, and the cabinet stoves at works J, the data relating to the upper stratum of air are included.

TABLE XIX.

Humidity of Back Draught Air.

Temperature Range of Back Draught	Well Ventilated Stoves				Badly Ventilated Stoves.			
	Mean Dry Bulb.	Mean Wet Bulb	Per cent Saturation	Drying Power	Mean Dry Bulb	Mean Wet Bulb	Per cent Saturation	Drying Power.
	°	°			°	°		
114·8° to 98·3°	105 0	79·6	30	25·4	104·4	77·4	26	27·0
95 3° to 87·0° ..	90·4	72·6	39	17·8	91·0	73·1	38	17·9
84·5° to 78·7° .	80·7	67 5	48	13·2	80·4	69·0	52	11·4

These figures show that according as the back draught had a temperature of about 80°, 90° or 105°, it got less and less saturated with moisture. Moreover, its degree of saturation was about the same whether the stoves were well ventilated or badly ventilated, these latter stoves in several instances having no structural ventilation whatever. It appears that the potters' stoves investigated ventilated themselves, for the steam pipes on the floor heated the air in their neighbourhood, and this air, rising by virtue of its lightness, automatically induced a fairly rapid circulation. The question at issue, therefore, is the amount and destination of the current of heated air. To what extent can it be prevented from passing back into the shop in the various types of stove, without prejudice to their drying powers?

Chamber Stoves.—It is evident that, in order to prevent back draught from chamber stoves, the doors must fit well, and they must be kept shut as much as possible. When a stove is in use it is customary to keep the doors open, as the potter, when carrying ware in or out, usually has both hands full. He may go in or out only once in five minutes, but still the doors are usually kept open. The swing doors introduced at works E did not solve the difficulty, as the men propped them open. It seems to me that it would not be a very difficult mechanical problem to provide each pair of doors with lever opening arrangements worked by foot. If the levers were connected with two foot plates situated just outside the doors, the potter, when approaching the entrance, could tread on the opening plate,

and when leaving it, could tread on the closing plate, without losing any time to speak of.

In chamber stoves used for drying articles such as plates, cups and saucers, the mould runner usually goes in and out every few seconds with a mould in each hand, and he often has to walk many miles a day in consequence. If he were to put his moulds of ware on a suitable tray, he would usually be able to carry four moulds instead of two. He would thereby halve the distance walked, and it might be worth while to open and shut the stove doors at each visit.

The ventilator from the roof of the stove should be fairly large, but with an opening easily capable of control. Trial experiments would probably show that the maximum drying power would be attained with a comparatively small amount of ventilation, for less heat would thereby be carried off, and though the air in the stove might be found to contain considerably more moisture in absolute measure, its relative humidity would be less and its drying power greater. It should be realised that the determination of the drying power of the air passing from a stove is a simple matter, dependent only on the reading of a wet and dry bulb hygrometer which has been kept in the current sufficiently long (ten minutes as a rule), to attain a steady temperature. It might be difficult to introduce the hygrometer into the ventilator pipe, or even at the entrance of the pipe, but the air escaping from a leak hole near the top of the chamber would usually afford a fair criterion of that going up the ventilator.

Dobbin Stoves.—In my experience, almost all dobbin stoves are badly constructed. The revolving dobbins do not fit closely to the doorways, and almost all of them allow large amounts of hot air to emerge at the top. It would be quite easy to prevent the escape of most of this air by fixing, at suitable places, strips and partitions of wood edged with felt. The bottom of the dobbin is often badly constructed as well as the top, in that it allows a great deal of cool air from the shop to pass in above the bed of steam pipes (and the boarding which usually rests on them) instead of underneath.

Draw-out Stoves.—The objection to the modern draw-out stoves at works E has already been stated. It can be reduced to some extent by forethought in the arrangement of the moulds on the sections. Most of the potters using the draw-out stove at works E were making several different kinds of plate each day, and each section had two or more different kinds of plate drying on it. In practice this meant that most of the sections were pulled out and allowed to cool in the shop twice a day, and some of them three times. Even if they were only pulled out once each, it would inevitably mean the transference of a good deal of heat from the hot moulds to the air of the shop. This transference is very much greater than that experienced with ware dried in other types of stoves, for the section and its contents is exposed to the shop for an hour or two, whilst moulds taken from chamber and dobbin stoves

are usually exposed only a minute or two, and thereby they lose a much smaller fraction of their heat.

The cooling of the moulds in the shop is disadvantageous in that it retards the warming up and drying of the fresh ware put on (or in) the moulds. For more than one reason, therefore, draw-out stoves fail to attain real efficiency. It is a mistake to make the sections too large, and it would probably have been better if those at works E had been built in two tiers, each 5 ft. high, instead of one tier 10 ft. high; or they might have had single shelves, and been of only half the width. If these two systems of division were combined, the sections would be only a quarter their present dimensions.

Cabinet and Mangle-type Stoves.—The cabinet stove at works J, though excellent for drying moulds, would not be suitable for drying clay ware. But evidently a closed stove is the ideal to be aimed at, and the mangle-type stoves at works L approached this ideal. The American drying stoves, recently described by Allen (1919), seem to be even better, for they not only prevent almost entirely the passage of hot air into the shops, but it is claimed for them that they likewise permit the temperature and humidity of the air to which the drying ware is exposed to be maintained at different levels during successive stages of drying, whereby the risk of cracking is greatly diminished.

It must be realised that the more perfect is a stove in retaining its heat, the more necessary will it be to instal a system of artificial heating in the shops. The actual amount of steam required would be no greater than that at present supplied during the winter months, for it would only mean that the steam saved through the better construction of the stoves would be diverted to a different channel. In the summer months there would be a considerable saving of steam, and throughout the year it would be possible to ensure suitable working conditions for the potters.

Drying Power of Stoves.—In so far as their drying power is concerned, the various types of stove examined do not show great differences when averaged, though the individual stoves varied between the extremes of 34·1 and 8·9. The drying powers of the back draught air (or of the upper strata of air in the chamber and cabinet stoves) recorded in Tables I to XIII are collected in Table XX. It will be seen that the average drying power was almost the same in summer as in winter, and it varied only from 16·2 to 25·3 in the various types of stove.

TABLE XX.

Relative Drying Powers of Various Types of Stove

Type of Stove.	Winter Observations		Summer Observations.	
		Mean		Mean
Dobbin	27·6, 21·3, 17·0, 16·0	20·5	29·9, 28·4, 13·1, 11·7	20·8
Cabinet	21·6, 10·7	16·2	34·1, 27·4, 14·4	25·3
Leaf and Draw-out	27·3, 17·7	22·5	19·9, 13·6	16·8
Chamber	22·6, 22·0, 20·0, 18·2, 15·9, 13·8, 13·4, 10·8, 8·9	16·2	20·2, 12·6	16·4
		18·9		19·8

No reliable information was obtained as to drying power in relation to the amount of heat supplied, but there can be little doubt that the mangle-type stoves at works L (the drying power of which is included in this Table) came first in this respect. Probably the cabinet stoves at works J came next, whilst the dobbin stoves, taken as a whole, came last.

A reference to Tables I to XIII shows that the drying power near the bottom of the stoves is usually only a half to a third as great as at the top. If the doors of a stove are closed, however, its drying powers become much more equalised. We saw that in the chamber stoves at works K the temperature and drying power was nearly constant at all levels 2 ft or more above the floor. It was likewise fairly steady in the cabinet stoves at works J, and probably it was moderately steady in the draw-out stoves at works E. If potters could be made to realise that closure of stove doors not only keeps the stoves at a higher temperature, but at a much more even temperature, they would take more trouble to enforce closure. As it is, they are not infrequently delayed because their ware does not dry fast enough, especially that stacked near the bottom of the stove. Where it is almost impossible to avoid keeping the stove doors open, it might be worth while to transpose the moulds in the top and bottom shelves during the course of the day, so as to equalise the drying.

SUMMARY.

Both on theoretical grounds, and as the result of actual experiment, it is concluded that in the drying of ware of moderate size high temperature is the chief requisite. A moderate amount of ventilation is essential, but this was already present in all of the stoves investigated, even in those entirely unprovided with ventilators. In their case the presence of structural defects in the stoves ensured adequate ventilation.

In proof of the relatively greater importance of high temperature than of rapid ventilation, let us suppose that one volume of air, on passing from shop to stove, is heated from 60° to 100°, or alternatively four volumes of air are heated from 60° to 70°. It is calculated that the drying power of the air at 100°, in so far as it depends on temperature, is four times greater than at 70°; but in so far as it depends on increased velocity, the drying power of the air at 70° would probably be only 25 per cent. greater than that at 100°.

In all stoves with the doors open there is a somewhat rapid current of cooler air passing in from shop to stove in the lower part of the doorway, and a similar current of hot air passing out from stove to shop in the upper part of the doorway. At some intermediate position, the "neutral point," air neither goes in or out, but ascends vertically, owing to the heat from the steam pipes.

The drying power of the outflowing air is usually about three times greater than that of the inflowing air, and though it contains a larger amount of moisture, it invariably shows a smaller degree of saturation, owing to its high temperature. The higher its temperature the less its saturation, and it was found that in badly ventilated or unventilated stoves the relative humidity of the back draught air was practically the same as that from well-ventilated stoves. The presence of steam pipes on the floor of a stove automatically ensures a good circulation of air. In unventilated stoves the whole of this air passes into the shop, but even in well-ventilated stoves as a rule over half of it passes back.

The back draught from chamber stoves can be greatly diminished by taking more care to keep the doors closed, and it is suggested that closure and opening should be effected by levers worked by foot. The back draught from dobbin stoves can easily be diminished by blocking the gaps at the sides and top of the dobbins. There is not much back draught from leaf and draw-out stoves, but in modern draw-out stoves there is a great transference of heat from the contents of the drawn out sections to the air of the shop.

Mechanical efficiency in the drying of the ware, coupled with the best workshop conditions for human efficiency, can be attained only by preventing nearly all back draught (or transference of heat from stove to shop in other ways), and by installing an independent system of warming the shops. Cabinet and mangle-type stoves approach the mechanical ideal, especially some of the stoves recently erected in this country and in America.

In conclusion, I wish to record my thanks to Mr. E. A. R. Werner, H.M. Superintending Inspector of Factories at Birmingham (and recently Inspector of Factories at Stoke), for the very valuable advice he so readily accorded me at all times.

REFERENCES

ALLEN, B. J. (1919): **Drying Stoves Scientifically Designed.** *Transactions of the Ceramic Society.* **19,** 26.

BIGELOW, F. H. (1910): **Studies on the Phenomena of the Evaporation of Water over Lakes and Reservoirs.** *Monthly Weather Review.* 307.

HANN, JULIUS VON (1915): **Lehrbuch der Meteorologie.** 3rd Ed. Leipsig. 215.

HILL, LEONARD (1919): **The Science of Ventilation and Open Air Treatment. Part I.** *Medical Research Council. Special Report Series, No.* 32. 27.

HILL, LEONARD, VERNON, H. M., AND HARGOOD-ASH, D. (1922): **The Kata-Thermometer as a Measure of Ventilation.** *Proc. Roy. Soc.* B. 93. 198.

NATIONAL COUNCIL OF THE POTTERY INDUSTRY (1920): *Interim Report on* **The Construction and Ventilation of Potters' Drying Stoves.**

Note by Sub-Committee of Panel Members.

The Sub-Committee mentioned on page 4, desire to point out that the effect of different methods of heating and ventilation involving different speeds and modes of drying on the quality of the ware produced still remains to be fully investigated. Many of the improvements recommended in this Report can, however, be safely acted upon forthwith and should be effected as far as possible without delay in the interests of the working potter.

As indicated on page 11 and elsewhere, many of the operatives themselves appear to prefer a working temperature of approximately 70°F (dry bulb), which is somewhat higher than that found most comfortable in other industries. This preference is largely attributable to the local cooling effect of constant contact of the hands with masses of moist clay. With adequate air movement and with proper ventilation maintaining a supply of pure fresh air, this higher temperature can in all probability be rendered consistent with healthy conditions generally.

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MUSCIO, B. (1921). Is a Fatigue Test Possible?—*Ibid.*, **12**, Part 1.

MUSCIO, B. (1921). Feeling Tone in Industry.—*Ibid.*, **12**, Part 2.

STURT, M. (1922). A Comparison of Speed with Accuracy in the Learning Process.—*Ibid.*, **12**, Part 3.

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To suggest problems for investigation, and to advise upon or carry out schemes of research referred to them from time to time by the Medical Research Council, undertaken to promote better knowledge of the relations of hours of labour and of other conditions of employment, including methods of work, to functions of the human body, having regard both to the preservation of health among the workers and to industrial efficiency; and to take steps to secure the co-operation of industries in the fullest practical application of the results of this research work.

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PREFACE.

Amongst industrial problems, the prevention of accidents, directly connected as this is with the alleviation of suffering, has always made a specially potent appeal to humanity. It is true that in the earliest codes of industrial legislation no reference is made to the subject of safety, but this silence can be explained partly by the necessity of dealing with the more pressing evils arising from unrestricted hours and conditions of living, and partly by a natural inability to appreciate immediately the consequences of substitution of mechanical for hand production. With the extending use of machinery, however, it quickly became clear that the increasing number of accidents called for legislation; in the United Kingdom, statutory requirements for the protection of the worker from injury were first embodied in the Factory Act of 1844, and at the present time provisions intended to promote safety of employment form a prominent feature in the industrial codes in all countries.

Apart from the legislative action that has been taken, non-official associations (such as the British Industrial "Safety First" Association in the United Kingdom, the National Safety Council in America, and in Italy, L'assoziane degli industriali per prevenir gli infortuni del lavoro) have been formed on a national basis with the object of inculcating on employers and workers the importance of reducing accident risk and of bringing to their notice new means of prevention as they are discovered In recent years, also, there has been an increasing tendency to set up special "safety committees" to deal with questions of accident prevention in individual factories [**2**, 16; **4**, 20; **13**].* Notwithstanding the large amount of attention that has been paid to the subject, however, there is still a large field to be explored in relation to the fundamental principles underlying accident causation. In order to obtain a clear insight into the nature of these principles, it is necessary to consider the special peculiarities of an accident as compared with any other occurrence.

In the first place, an accident being a wholly unfavourable occurrence,† no question of compromise arises in its investigation. Total elimination is the ideal aimed at, and not, as in the case of many other industrial problems, the discovery of some optimum condition.

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* The thick figures denote the references given on p. x, and the ordinary figures the pages of the references in question.

† Etymologically, of course, the word has no unfavourable subaudition, being equivalent merely to "unforeseen event." In this respect it differs from the German "unfall" (mischance) and the Italian "infortunio" (misfortune) both of which have definitely unfavourable significance.

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Secondly, an accident is essentially an unexpected and unpremeditated event,* a feature which has been specially recognised in judicial interpretation of the Workmen's Compensation Acts.† Hence investigation of the cause of the accident whilst it is actually *in operation* is generally impracticable, and the circumstances contributing to it can only be inferred after it has actually occurred.

Finally, an important characteristic of an accident is that cause and effect are, as a rule, unrelated in magnitude; in other words, whilst forecast of the *type* of injury produced by a given type of accident is often possible, forecast of the *extent* of injury is not. The same exciting cause, for instance, may entail anything from a trifling burn to a disastrous explosion involving heavy loss of life. The important practical conclusion follows that for certain purposes the *effects* of accidents may be left out of consideration when studying their causation.

Up to the present accidents have been studied chiefly from the humanitarian point of view, and attention has been primarily directed to those involving a certain standard of injury. Thus, under the Notice of Accidents Act, 1906, compulsory notification of industrial accidents is confined to those which result in absence from work for at least seven days or (in the case of certain specified causes) for one day. In addition to this class of accident, a host of comparatively trivial accidents are incurred every year, which not only cause pain and inconvenience, but are a source of heavy economic loss. Indeed, it is possible that the economic effects of these are in the aggregate greater than those of the major accidents.

The total number of accidents of all kinds incurred in a year is, of course, unascertainable. Vernon [**33**, 180] found in certain munition factories that notifiable and other accidents occurred in the ratio 1 to 30, and whilst this proportion may not hold for all industries, he thinks it safe to assume that the general ratio is at least 1 to 10.‡ If this assumption is accepted, it means that in 1920, 1,400,000 minor accidents were incurred. If it is further assumed (of course, quite arbitrarily) that, taking into account the temporarily decreased productive capacity following an injury, each minor accident involved on the average absence from work for half a day, the number of worker-days lost through this type of accident alone amounted to 700,000.§

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* An intentionally preposterous illustration of this characteristic will occur to readers of "Through the Looking Glass," in which the White Queen is described as screaming some minutes before she pricks her finger.

† Lord Macnaghten's definition of an accident is "a mishap or untoward event not expected or designed."

‡ In an American wood-working and machine shop plant the incidence of major and minor accidents was in the ratio of 1 to 80, but the numbers employed (115) are far too small to admit of generalisation. [**26**].

§ This estimate applies only to factories and workshops. If other industrial occupations (e.g., mining and railway working) were included the loss would doubtless be much greater.

In any case, it is certain that quite trivial accidents may and do entail a heavy loss in production.*

Accidents of this kind are also important in another respect. Since, as has already been pointed out, the cause and effect of an accident are unrelated in magnitude, it is immaterial for the study of certain aspects of causation whether the result of the accident is serious or not, and, hence, data relating to trivial accidents can with certain precautions be used to draw conclusions applicable without modification to accidents generally.

Every accident obviously has an initial cause. In some few cases it is well defined; in most, however, it is complex, but it may always be regarded as being composed of two factors, one impersonal (relating to the object, material or machine) and the other personal (relating either to the person injured or perhaps to some other person). If accidents could be classified according to the relative importance of these two factors, we should have at one extreme accidents due to the unforeseen failure of material, such as the bursting of a wheel, and at the other those, due entirely to "carelessness," and incurred on a machine or other object regarded as ordinarily quite safe [**9,** 259; **10,** 6].

The above distinction implies that accident prevention can be brought about in two ways:—

(*a*) by eliminating the predisposing cause through study of the personal factor; and

(*b*) by limiting the effect produced by the operation of the predisposing cause.

Of these, the second has received most attention in the past, but it is unjustifiable to assume, as is sometimes done [**10,** 39], that accident incidence in any given factory has reached its minimum until the first has been fully explored [**35,** 337].

Up to the present, progress in accident prevention has been made chiefly through the study of the impersonal factor. Questions of safety devices, guards for dangerous machinery, and machine design are continuously being investigated, with the object of reducing accident risk to a minimum. The influence of the personal factor has also been recognised practically to some extent, and much has already been done by the issue of posters and other methods of propaganda to impress on the workers the importance of exercising care, and to indicate the various ways in which accidents are likely to occur. The study of it from a scientific point of view is, however, still in its infancy.

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* The above figure indicates of course the time lost *during the year in question*. As an illustration of the ultimate economic effects of accidents, it may be pointed out that a recent Committee of Inquiry, using a different method of computation, have estimated that the accidents of all kinds incurred in the United States in a single year (1919), represent a loss in *future* production equivalent to no less than 296,000,000 worker days. [**35,** 331].

The importance of the personal factor has been officially recognised [**13**], as in the following quotation :—

> "It is perhaps not generally realised that machinery is responsible for only a minority of the accidents which occur in factories and workshops The Home Office records show that more than two-thirds of such accidents are due to other causes. The annual reports of the Home Office Inspectors regularly show that a great number of accidents are due simply and solely to carelessness, inattention, and want of thought. It has been estimated that the percentage of avoidable accidents in some industries is as much as 60 per cent."

Specific information on this point is small, but so far as it exists, it goes to prove that the personal element plays a much larger part in accident causation than is generally supposed. Of the fatal accidents incurred in coal mines during 1921, for instance, the accidents preventable by the action of the individual were found to represent 33 per cent. of the total [**12**]. Similarly from a summary of the accidents sustained on power presses in this country during 1920 [**3**, 31], it appears that about 75 per cent. of the accidents were due in some degree to "lack of care or judgment on the part of the operator or interference with the safety devices," and in a return published by an American textile mill [**21**] about 25 per cent. of the accidents incurred are ascribed to "carelessness" on the part of the worker.

The view has always been held that the principal personal elements in accident risk are fatigue and speed of production [**15, 22, 24, 25**]. This was explicitly recognised by the Departmental Committee on Accidents in Places under the Factory and Workshop Acts [**1**], though they were unable to obtain definite numerical data in support of their opinion. On this point they remark (p. 16) :—

> "We have been unable to get any scientific evidence as to industrial fatigue, but as these tables* seem to point to an interesting correlation between the hour of employment and accident risk, we suggest that it would be instructive to take fatigue measurements by some of the recognised scientific tests of a number of workers in cotton mills, with a view to discovering whether there is any correlation between the degree of fatigue and the accident risk."

In recent years much discussion has circulated round the personal factors of the accident causation [**8, 9, 15, 17, 18**], and actual investigation has been carried out in two ways. On the one hand, data of actual accidents have been collected, and from the type of incidence certain deductions have been drawn as to the probable fundamental causes. On the other hand, laboratory research has been undertaken with the object of discovering the causes tending to induce conditions which may reasonably be regarded as analogous to those rendering a worker specially prone to accident.

The former kind of investigation has consisted chiefly in tracing the hourly incidence of accidents throughout the working

* The tables referred to show that in cotton spinning mills the highest accident rates occur between 10 and 11 a.m. and between 3 and 4 p.m.

day.* From a full analysis of these given by the British Association Committee on Fatigue from an Economic Standpoint [**9**] and by Frankfurter and Goldmark [**18**], it appears that the usual type of curve shows a rapid increase in accident rate during a day's work, reaching a maximum during the last or penultimate hour of the morning, a similar trend being frequently observed in the case of the afternoon spell. On the basis of these characteristics, it has been frequently concluded [**6, 23, 25**] that fatigue is the most important factor in accident causation. It is, however, acknowledged [**8**, 305; **31**, 4] that all of these earlier investigations suffer from one defect, namely, that the effect of variations in activity were not taken into account, owing to the impossibility of correlating the accident rates with rates of output.

In an investigation into more than 50,000 accidents incurred in munition factories [**31**], in which the variations in output throughout the period were measured simultaneously with the variations in accident incidence, Vernon succeeded in establishing the influence of this factor, and also showed the existence of a third factor, namely, the psychic state of the worker. His main conclusions may be summarised as follows :—

(*a*) The strong qualitative resemblance between the rate of output curve and the accident incidence curves during the day shift shows that varying speed of production is largely responsible for the day shift variations of accidents, and *not* fatigue.

(*b*) That fatigue may be an important contributing cause, however, is shown by the fact that during a period when a 12 hour day (75 hour week) was being worked the accidents incurred by women were two-and-a-half times more numerous than in the subsequent period when the daily hours were reduced to 10.

(*c*) In addition to speed of production and fatigue, an important part is played by psychical influences, such as alertness and attention. This conclusion is based on a comparison between the accident incidence on the day shift and on the night shift. Whereas in the former the accident curve follows the output curve very closely, in the latter it is widely different. Here the accident rate is at a maximum at the beginning, then falls sharply and finally sinks to less than half the original value. Further, the total accident rate is lower by an average of 16 per cent., with no decrease in output. Vernon ascribes these differences to psychical influences, assuming that the night workers started work in a careless and excited state and gradually settled down to a calmer mental state than the day workers.

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* Probably the earliest data of the kind collected in this country are contained in the Annual Reports of the Chief Inspector of Factories for 1910 and 1911, but these accidents are necessarily confined to those notifiable to Inspectors of Factories and do not include the more trivial kind

Simultaneously with these investigations, Bogardus [**15**] and others have studied in the laboratory the conditions under which "accuracy of movement" diminishes.

The net result of the work done is to show that amongst the factors normally operating in accident causation, an important part is played by speed of production, fatigue and the psychic state of the injured person, and the more recent investigations have been largely concerned with studying the relative importance of these three factors.

In 1920 the United States Public Health Service published a report [**5**] embodying the result of an investigation into 46,000 accidents in two engineering plants in America. The method differed in some respects from that adopted by Vernon. Instead of comparing the output curve with the accident incidence curve, the authors (following a suggestion put forward by the Committee of the British Association in 1915 [**8**]) took as a criterion a number expressing accident rate per unit of output, claiming that this should remain constant if accident incidence depended solely on speed of production. Their conclusions are that though, in the absence of fatigue, accidents vary directly with speed of production owing to increased exposure to risk, this regular variation is broken up by fatigue, which plays an important part in accident causation. In this report Vernon's views as to the relative importance of speed of production and of fatigue are discussed, and his results criticised mainly on the grounds that they were derived from machine work, which gives the least evidence of fatigue.

In the present report some further light is thrown on the subjective aspect of accident causation, and in particular on the parts played respectively by speed of production, psychical state of the worker, and fatigue.

In Part A a reply is made by Osborne and Vernon to the criticism already mentioned. Briefly, it maintains that in the U.S. Public Health Service investigation no account was taken of the psychic factor, which, according to Vernon, is of great importance. A striking confirmation of this is shown by some data relating to night-shift accidents obtained in the course of the American investigation but not included in their report, and subsequently published by Ryan [**28**]. The curve of accident incidence follows roughly the same course as that obtained by Vernon for night-shift workers, and also differs markedly from the curve for day-shift workers. Similarly, Vernon's view that speed of production is the important factor is supported by the results of the experiments conducted by Muscio and described in Part B of the present report. The data given clearly suggest that accuracy of movement diminishes as the rate of work increases, whilst it actually increases over a continuous spell of three-and-a-half hours when the rate of work is uniform. It was even found possible by gradually increasing the rate of movement through a spell of work to obtain a curve broadly resembling the typical accident curve for the morning spell.

But in dealing with accident incidence, yet another consideration must be taken into account. In addition to the total number of accidents and the immediate factors in their causation, the question of their *distribution* and of the causes which under equal conditions of risk render some parts of the working population more prone to accidents than others is of great importance.

An investigation carried out by Greenwood and Woods [**20**] on data collected in munition factories during the war indicates that distribution of accidents is largely influenced by a special personal susceptibility inherent in the individual and differing from one individual to another. Their report suggests, indeed, that this personal susceptibility may be a much more material factor in accident causation than is generally supposed, for it not only shows by statistical proof that in regard to accidents all workers do not start equal, in that some are more liable to suffer casualties than others, but also affords grounds for thinking that the bulk of accidents may occur amongst a limited number of individuals having a special personal susceptibility to accidents.

The further study of this fundamental question of susceptibility is undoubtedly called for in the interests of accident prevention, since, if the importance of special susceptibility as a factor in accident frequency is confirmed and the qualities which constitute it can be determined, the introduction of some system of selection on the basis of the accident risk of the work becomes a practical possibility [**20**].

Another important factor in liability to accidents is undoubtedly inexperience. Verney, for instance [**30**], in a statistical study dealing with the apparent increase of accidents during the years preceding 1910, has adduced evidence to show that notifiable accidents increased three times as fast as the volume of manufacture, and that half of this increase was due to the greater speeding up and to the engagement of young and inexperienced persons, the other half being only apparent and due to better reporting on the part of the employers. Further, the Committee of the American Public Health Service [**5**] found a high degree of parallelism between the accident rate and the proportion of inexperienced men, and evidence pointing to the existence of the same cause is also given in a report dealing with accident incidence in the iron and steel trade [**16**].

Age may also play a part. Age and inexperience coincide to a large extent, since the majority of new entrants are young people, but irrespectively of this there are certain qualities of youth (such as bravado, failure to realise danger, etc.) which tend to disappear with increasing age.* Hence, one would expect

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* The greater susceptibility to accidents of young workers is recognised in the Factory and Workshops Act, 1901, sections 12 and 13 of which impose restrictions on the employment of children and young persons in respect of certain classes of machinery.

to find a proportionately higher accident incidence amongst the younger population of a factory, apart altogether from experience of the work. Information on this point is contained in an analysis of accidents incurred in an American textile mill [**21**], from which it appears that the accident rate per 100 workers diminishes from 30 for workers between fifteen and twenty years of age, to 19, 17, and 12 for the next succeeding quinquennial age groups, and an almost identical conclusion has been reached in the case of an investigation in another textile mill [**19**]. In a large American steel plant also, in which " the young men were employed along with older men in occupations likely to produce many cases of short term disability," the accident frequency rate for workers under 20 was twice that for workers aged 20–29, and more than three times that for workers aged 30–39.

Finally, another factor which cannot be wholly disregarded is alcohol, more especially as in other occupations there is direct evidence that it is sometimes a contributing cause of accident [**7,** vi]. Vernon has shown [**32, 34**] that diminished neuro-muscular control follows the consumption of alcohol, excepting in very moderate quantities, though there is a marked difference in this effect according to the circumstances. A subject used to alcohol is, as would be expected, less affected than a total abstainer, and, again, alcohol taken on an empty stomach has apparently a much greater effect than alcohol taken with food. Vernon also [**31**], by comparing accident incidence during two periods during the war in which the licensing restrictions differed, has pointed out that with reduced opportunity for drinking the accidents incurred by men showed a decline as compared with those incurred by women, and suggests that this may be due to lessened consumption of alcohol on the part of the former.

In addition to the qualities inherent in the individual, extrinsic conditions (such as environment) have been proved to bear a close relation to accident incidence. Thus, self-protection on the part of the worker from a potential danger is often dependent on rapidity of vision, and this in turn is affected by the nature of the lighting at the time. Inadequate or unsuitable lighting has in fact been shown to be an important contributing cause of accident [**11, 14**].

Similarly, the temperature of the worker's environment seems to have considerable influence on accident risk. In Part A of the present report it is shown that for engineering work there is probably an optimum temperature (67.5° F.) at which accident incidence is at a minimum, an increase occurring with either a rise above or a fall below this limit. This directly confirms the conclusion based on the results of a previous investigation by Vernon [**31**], that accidents were at a minimum at temperature between 65° and 69°, increasing rapidly at higher temperatures and slowly at lower temperatures.

The Board have felt it desirable to discuss the subjective side of accident causation in some detail, in order to indicate the extreme complexity of the problem. This complexity may, they think, arise in two ways. In the first place, it is due to the number and the elusive nature of the factors operating, which make their isolated study specially difficult. May Smith, for instance, has shown [**29**] that fatigue, when estimated objectively, seems to involve two phases ; during the first it acts apparently as a stimulant, and during the second, which is of much longer duration, there is a general loss of accuracy of aiming and other indications of diminished neuro-muscular co-ordination. On the other hand, the subjective feelings of fatigue bear no relation to the objective demonstrations, so that a given subject may often be unaware of his condition. On this May Smith remarks :—

> "The possibility of the second phase of fatigue extending far beyond the subjective indications is of urgent importance industrially. It has been shown that fatigue involves at least loss of accuracy, failure of memory, lowering of speed ; where such inefficiency, instead of displaying itself in the secrecy of the laboratory, imperils the life of the worker himself or of others, the problem becomes momentous It is highly probable that a connection might not be realised between fatigue and an accident, if the latter occurred considerably after the fatiguing experience, and yet it is just when the strain ceases to be felt, and the vigilance, therefore, is relaxed, that the greatest danger occurs"

Secondly, the factors themselves are not independent, but often have important mutual relations. Thus, it has been shown that accident risk may depend both on speed of production and on fatigue. But in many operations speed of production decreases as fatigue increases, so that fatigue may sometimes have an actually protective effect [**6**]. So, also, alcohol appears to have different effects according to whether it is consumed during normal or during fatigued conditions [**27**]. In the latter case it acts deleteriously during the stages of increasing inefficiency induced by excessive fatigue, but acts "beneficially" as the subject later begins to revert to normal efficiency.

November, 1922.

REFERENCES.

[1] (1911) Accidents in Places and Under the Factory and Workshop Acts Report of the Departmental Committee on, (Cd 5535)

[2] (1919) Annual Report of the Chief Inspector of Factories for 1918 (Cmd 340)

[3] (1921) Annual Report of the Chief Inspector of Factories for 1920 (Cmd 1403)

[4] (1922) Annual Report of the Chief Inspector of Factories for 1921 (Cmd 1705)

[5] (1920) Comparison of an Eight-hour Plant and a Ten-hour Plant (*Public Health Service Bulletin No* 106, *Washington.*)

[6] (1911) Condition of Woman and Child Wage-earners in the United States, Report on *Senate Document No* 645, 1, 395

[7] (1915) Deaths of Seamen and Fishermen reported to the Board of Trade in the year ended June 30th, 1914 Return of the, (Cd 940)

[8] (1916) Fatigue from the Economic Standpoint Committee on, First Interim Report (*Brit Ass Rep*, 1915)

[9] (1917) Do Second Interim Report (*Brit Ass Rep*, 1916)

[10] (1920) Industrial Safety Conference, Report of Proceedings. p. 44 (*H M Stationery Office*)

[11] (1915) Lighting in Factories and Workshops. First Report of Departmental Committee on, (Cd 8000)

[12] (1922): Parliamentary Debates (House of Commons). 156 92 Col 629

[13] (1918). Safety Committees in Factories and Workshops (*H M Stationery Office.*)

[14] (1911) U.S Travellers' Insurance Co Report of

[15] BOGARDUS, E. S (1911) · The Relation of Fatigue to Industrial Accidents (*Amer Journ Sociol*, **17**, 206, 351 512)

[16] CHANEY, L W and HANNA, H S (1918) The Safety Movement in the Iron and Steel Industry, 1907 to 1917 (*Bureau of Labor Statistics, No* 254, *Washington*)

[17] COLLIS, E L and GREENWOOD, M (1921) *The Health of the Industrial Worker.* (J & A Churchill, London)

[18] FRANKFURTER, F and GOLDMARK, J (1917): *The Case for the Shorter Work Day* (National Consumers' League, New York)

[19] GATES, D S. (1920) A Statistical Study of Accidents in the Cotton Mills. Print Works and Worsted Mills of a Textile Company (*Journ. Ind Hyg* **2**, 8)

[20] GREENWOOD, M and WOODS, H. (1919) · The Incidence of Industrial Accidents upon Individuals, with Special Reference to Multiple Accidents. (*Ind. Fat Res Board, Report No* 4.)

[21] HEWES, AMY (1921) Study of Accident Records in a Textile Mill (*Journ. of Ind Hyg.* **3**, 6)

[22] IMBERT, A. (1904) 14th International Kongr f Hyg und Demog II. 634.

[23] IMBERT, A (1904). Les accidents du travail et les compagnies d'assurance *Revue Scient*, *June* 1904, 15

[24] IMBERT, A and MESTRE, M (1905) Nouvelles statistiques d'accidents du travail *Ibid*, Oct 1905, 521

[25] LE ROY (1906) *Bulletin de l'Inspection de Travail,* **324,** Paris

[26] MCCORD, C P and MINSTER, D K (1922) · Adequate Industrial Medical Service for the Small Plant (*Jr Ind Hyg* **3**, 12)

[27] MCDOUGALL, W and SMITH, MAY (1920) · The Effects of Alcohol and some Other Drugs during Normal and Fatigued Conditions (*Med Res. Counc*, *Spec Rep Ser No* 56)

[28] RYAN, A. H. (1921) Discussion of Public Health Bulletin, No 106, Comparison of an Eight-hour Plant and a Ten-hour Plant (*Jr Ind. Hyg* **2**, 12)

[29] SMITH, MAY (1916) A Contribution to the Study of Fatigue. (*Brit Journ of Psych.*, 8, 3)

[30] VERNEY, H (1910). On the Recent Considerable Increase in the Number of Reported Accidents in Factories (*Journ Roy Statist. Soc.*, **78**, 2)

[31] VERNON, H M (1918) · An Investigation of the Factors Concerned in the Causation of Industrial Accidents (*Health of Munition Workers' Committee*, *Memo No* 21) (Cd 9046)

[32] VERNON, H M. (1919). The Influence of Alcohol on Manual Work and Neuro-Muscular Co-ordination (*Med Res Counc Spec. Rep. Ser No.* 34)

[33] VERNON, H M (1921): *Industrial Fatigue and Efficiency* (Routledge & Sons, London)

[34] VERNON, H. M (1921): Alcohol and Industrial Efficiency. (*Brit Journ of Inebriety,* **18,** 109)

[35] WILLIAMS, S. J (1921): *Section on Industrial Accidents* in "*Waste in Industry*" (McGraw Hill Book Co, New York)

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TWO CONTRIBUTIONS TO THE STUDY OF ACCIDENT CAUSATION.

A.—THE INFLUENCE OF TEMPERATURE AND OTHER CONDITIONS ON THE FREQUENCY OF INDUSTRIAL ACCIDENTS.

BY ETHEL E. OSBORNE, M.Sc., AND H. M. VERNON, M.D.,
Investigators to the Board.

I. INTRODUCTION.

In a previous report * one of us described the frequency and incidence of the accidents occurring under various conditions in several munition factories. Among these conditions, temperature was found to have a very marked influence, for at two of the factories, where the heating arrangements were inadequate, the number of accidents experienced on those days of the year when the temperature outside was at or below freezing point was 40 per cent. to 140 per cent. greater than on warm days, when it was at or above 48°F. No determinations of the temperatures inside these factories were made, though at another factory a continuous record was obtained for a six month period by means of a thermograph. This record indicated a well-marked relationship of accidents to temperature, but the factory was so well heated that temperatures below 55° were very seldom observed. It seemed worth while, therefore, to obtain continuous records at the inadequately warmed factories, in order to find out the effect of a greater range of temperature on accident frequency.

II. TEMPERATURE RECORDS AT A PROJECTILE FACTORY.

One of the two factories investigated (previously described as Factory C) was devoted entirely to the production of 9·2 inch howitzer shells. It consisted of two large shops of similar size and internal arrangement, and near the centre of one of these shops a copper-bodied thermograph was installed at a height of about five

* Memorandum No. 21 of the Health of Munition Workers Committee, on "The Factors concerned in the Causation of Industrial Accidents" 1918 (Cd. 9046.)

feet above floor level. Its accuracy was frequently checked against a standardised thermometer fixed near by, and by its means a continuous temperature record was obtained from January to October, 1918.

The factory employed about 1,800 workers altogether, of whom slightly more than half were women. The numbers were very steady throughout the observational period, and the output was likewise fairly steady, for between February and September the monthly output varied only by 16 per cent. The times at which the accidents were treated were recorded in case books at the ambulance room, and the nurses were enjoined to be very careful in distinguishing between all cases treated for the first time, and re-dressings. A close supervision was kept over them, and we believe that their records are quite reliable. This was not always the case in the records of this factory described in the previous report, though the very much larger number of records obtained at a fuse factory (on which the main conclusions arrived at were based) were thoroughly reliable. The accidents were tabulated under several headings, but for purposes of temperature investigation we have confined ourselves to cuts. Cuts formed over 70 per cent. of all the accidents treated, and they afford a reliable guide of accident incidence, in that sufferers from them come at once to the ambulance room for treatment, with few exceptions.

The men and women at the factory worked the same hours, viz., 48 per week when on day shift, and 60 per week when on night shift, and they changed shift every week. Each shift consisted of three work spells. The duration of these spells is recorded subsequently, and reasons are given why the periods over which the accidents were enumerated are those given in Table I, and not the full length of the spells. The average temperature during each spell was read from the thermograms, according as it fell between

TABLE I.

Accidents at projectile factory in relation to temperature.

Time of spell for which cuts were enumerated.	Men						Women.					
	50° to 54°	55° to 59°	60° to 64°	65° to 69°	70° to 74°	75° or more	50° to 54°	55° to 59°	60° to 64°	65° to 69°	70° to 74°	75° or more.
Day Shift :—												
7.30 to 9 a.m.	·75	1·02	65	·78	71	—	1 50	88	1·01	96	57	—
10 15 to 12 30 p.m	2 00	1 61	1 50	1 48	1 39	1 42	2 00	1 78	1 90	1·77	1 10	1 33
2.30 to 5 p m.	2·00	1 75	1 40	1 15	1 03	1 38	3 00	1 44	2 05	1 44	1·16	1 24
Night Shift :—												
8.15 to 11 p m.	1 50	1 50	1 34	1 29	1 15	3 00	1 91	2 60	2 07	2 08	1 90	2 00
1 to 3.15 a.m	1·00	·92	99	·86	·57	—	1 50	2 08	1 42	1·34	1·29	—
4.45 to 7 a.m.	1 00	1 02	·80	·70	·33	—	1 50	1 09	1·24	1·09	1·00	—
Average number of cuts in each spell ..	1 37	1 30	1 11	1 04	86	(1·48)	1·90	1·65	1·62	1·45	1 17	(1·26)
Total number of spells investigated ..	25	213	422	280	110	48	25	213	422	280	110	48

the limits of 50° to 54·9°, 55° to 59·9°, and so on, up to a temperature of 75° or more As can be seen from the Table, this upper range of temperature was observed during only 48 work spells, whilst a temperature of 60° to 64° was observed during 422 spells. Temperatures of 50° to 54° were observed only on 25 occasions, and no spell showed an average temperature of less than 50°. Hence it follows that the heating of the factory was fairly adequate. It had been improved since the previous year ; also the winter was a much milder one.

The table records the average number of cuts experienced in all the six spells at each temperature interval. Temperatures of 75° and upwards did not occur at all during the first day shift spell and the last two night shift spells, so the average number of cuts per spell was calculated on the supposition that the same proportionality held between cuts in all the spells and those in the three intermediate spells as was found to hold, on an average, during all the other temperature intervals.

It will be seen that both men and women experienced a minimum number of cuts at 70° to 74°, and that at higher temperatures there was a sharp rise. At temperatures below 70° to 74° the accident frequency gradually increased, and reached its maximum at 50° to 54°, both in men and women.

III. Temperature Records at a Shell Factory.

Another series of thermograph records was obtained at a factory devoted exclusively to the manufacture of 6-in. shells (factory B of the previous report) The instrument employed was enclosed in plate glass, and on that account was slower in responding to temperature changes than the copper-bodied thermograph used in the projectile factory, but no substantial error would be produced thereby in the results. It was set up near the middle of the single large shop which constituted the factory. It was running for a continuous period of twelve months (October 1917 to October 1918), but owing to a strike the number of work spells for which records were obtained (viz., 1,248) was not much greater than that at the other factory (viz., 1,098). The output from the factory was steady, as the monthly output varied only 13 per cent. during the course of the year. The number of men employed was likewise steady, but in February 1918 the women, who had hitherto been on a two-shift system, were changed over to a three-shift system. Their number had to be increased proportionately, but the ratio between the number of women and number of men actually at work in the factory was still approximately as two to one, so the frequency of accidents was not affected, except indirectly as the result of diminished fatigue. Previous to the change both men and women were on a $10\frac{1}{2}$-hour day, and

they worked 59 hours a week on day shift and 63 hours on night shift in alternate weeks. After the change the women averaged 39½ hours a week. The total number of workers was approximately 2,100.

Table II is arranged on the same system as the previous one, though the times of the work spells are different. It will be seen

Table II.

Accidents at shell factory in relation to temperature.

Time of Spell for which cuts were enumerated.	Men.						Women.					
	49° or less	50° to 54°	55° to 59°	60° to 64°	65° to 69°	70° or more	49° or less	50° to 54°	55° to 59°	60° to 64°	65° to 69°	70° or more.
Day Shift—												
6 30 to 8 45 a m	91	1·16	91	1·02	57	—	1·86	1·95	1·94	1·58	1·57	—
9 45 to 12 45 p m	1·65	1·33	1·07	·91	1·00	75	2·59	2·28	2·25	1·83	2·35	2·50
2 30 to 5 30 p m .	1·00	1·16	1·20	96	1·00	1·00	2·36	2·56	2·37	1·89	1·76	2·25
Night Shift—												
6 30 to 8 45 p m .	1·17	1·94	1·07	·93	·85	1·00	2·33	3·30	1·91	1·58	1·41	1·58
10.15 to 1 15 a m. .	1·41	1·27	1·17	95	83	2·00	2·06	1·86	1·71	1·80	1·12	·80
2.30 to 5.30 a m. .	1·00	91	·73	95	1·15	—	1·89	1·49	1·89	1·54	1·69	—
Average number of cuts in each spell	1·19	1·29	1·03	95	90	(1·11)	2·18	2·24	2·01	1·70	1·65	(1·69)
Total number of spells investigated	103	286	377	340	109	33	103	286	377	340	109	33

that no temperatures of 75° and upwards are recorded; but on the other hand, temperatures below 50° were observed on no less than 103 occasions. The accident frequency at these low temperatures was somewhat less than at 50°–54°, both in men and women. Such an apparently contradictory result may have been due to the workers to some extent working slower at the very low temperatures, or ceasing work altogether, but we have no direct evidence to support this hypothesis.

It will be seen that the temperature interval of minimum accident frequency was at 65°–69°, and not at 70°–74°, as at the projectile factory. It is true that the women showed very little difference in accident frequency as between these two temperature intervals, but the men showed a well-marked rise at the higher interval. The discrepancy between the results is smaller than it seems, and it is due partly to the different systems of heating at the two factories. At the projectile factory hot air was driven down on to the heads of the workers by pipes opening about 12 ft. above their heads, and the temperature of the air at head level (which was recorded by the thermograph) was several degrees

above that at foot level. At the shell factory the heating was by means of steam pipes, and the system, though inadequate, effected a more even distribution of the heat.

The difference in the temperature of minimum frequency at the two factories may be due in part to the differences in the character of the work performed. The processes of manufacture of the two sizes of shell are very similar, but they take about twice as long for the larger-sized shell as for the smaller one, and in consequence there is usually more waiting and standing about. At the fuse factory described in the previous report almost all the operations were of much shorter duration than those required in shell making, and in many or most cases they entailed more activity on the part of the workers. Probably for this reason the temperature of minimum accident frequency was found to be 65°–69°, and there was a sharp rise of accidents (cuts) experienced at higher temperatures.

A comparison of the accident frequencies observed at the three factories is shown in Table III. At the fuse factory accident data for each of the five spells (in the 24 hours) were observed

TABLE III.

Relative frequency of accidents in relation to temperature.

Factory	Sex of Workers.	49° or less.	50° to 54°	55° to 59°	60° to 64°.	65° to 69°.	70° to 74°.	75° or more
6-in. shell factory ..	Men	132	143	114	106	100	123	—
,, ,, ,, .	Women	132	136	122	103	100	102	—
9·2-in projectile factory..	Men	—	132	125	107	100	83	142
,, ,, ,, ..	Women	—	131	114	112	100	81	87
Fuse factory .. .	Men	—	—	103	104	100	101	136
,, ,, ...	Women	—	—	120	106	100	139	127
Mean for all factories	Men	132	137	114	106	100	102	139
	Women	132	134	119	107	100	107	107
	Men & Women	132	135	116	106	100	105	123

only in the 60°–64° and the 65°–69° temperature intervals, so the average number of cuts per spell for such spells as were missing in the other temperature intervals was calculated on the same principle of proportionality as that employed with the data from the other two factories, the 60°–69° figures being used as the standard. The frequency at 65°–69° is in each case taken

as 100, and it will be seen that though the results obtained at the individual factories are rather irregular, they yield a fairly regular series of values when averaged. The only real irregularity is the fall in accident frequency at temperatures below 50°. This may be an error, due to insufficiency in the number of records, or it may be due to the workers reducing their rate of production, and thereby their liability to accidents, in very cold weather.

In Fig. 1 are reproduced the separate results for men and women, as well as the mean. It will be seen that the separate results for men and women show that at temperatures below 67° the accident frequency was influenced to about the same extent in both sexes, but at temperatures above 67° the men were affected more than the women. Probably this is because their work was often of a heavier character, and the greater the exertion required the more trying must be the effect of exposure to high temperatures.

The observations recorded in the previous report showed that women were more affected than the men. We are at a loss to account for the discrepancy, but possibly the women learnt wisdom by experience, and got into the habit of clothing themselves more warmly in cold weather.*

It should be borne in mind that the best temperature for accident prevention is not necessarily the most suitable one for

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* Since in some cases the numbers of observations are somewhat small, Miss Newbold and Miss Allen (statistical investigators to the Board) kindly analysed some of the data with a view to determining whether the whole system of deviations is such as might have arisen by chance in sampling a "universe" wherein the liability to accident was unaffected by temperature. The method they have adopted was the following:—

Supposing one has a series of records of the number of accidents sustained in a fixed work period (e.g., the first spell of the day) by a constant, or approximately constant, number of workers for different temperatures. Suppose that the total number of accidents is M and the total number of observations, i.e., of observed spells, is N, and that n of these were worked under a particular temperature T. Then if temperature does not really affect the number of accidents, the number which would be expected under temperature T is merely n/N multiplied by M, the whole number of accidents, and similarly for other ranges of temperature. The extent of agreement between these "theoretical" and the actually observed numbers of accidents may then be tested by well-known methods.

This has been done by Miss Allen and Miss Newbold for 24 sets of data. The results show that in many instances, indeed in a majority, the divergence between the "theoretical" and the observed number of accidents is not so great, but that the divergence might feasibly have arisen owing to the fluctuations of chance. But if the whole set of 24 constants of agreement at the two shell factories (the constant used to test Goodness of Fit, and denoted by P) be compared with the distribution of such constants as would be expected were pure chance to be responsible, the proportion of "good" fits is much less and of "bad" fits much larger than the expected numbers. Hence the conclusion must be drawn that it is practically impossible that the relation between temperature and accidents brought out in our curves is a mere chance of fluctuation.

For a discussion of the method *see* G. Udny Yule's, "Introduction to the Theory of Statistics," 5th edition, 1919, pp. 378–80.

working efficiency. There can, in fact, be little doubt that a temperature of 67° is too high for the attainment of maximum efficiency if the work is at all active, though we have no exact information as to what constitutes the best temperature. At an American factory (1) the rooms where the men were engaged on moderately active work were kept at 65° to 67°, so far as possible, whilst in the smith's shop and carpenter's shop, where active work was the rule, it was kept at 55° to 65°. In this country a number of temperature records were taken at factories "where complaints were infrequent" (2), and it was found that in shops where light machine work was performed the temperatures

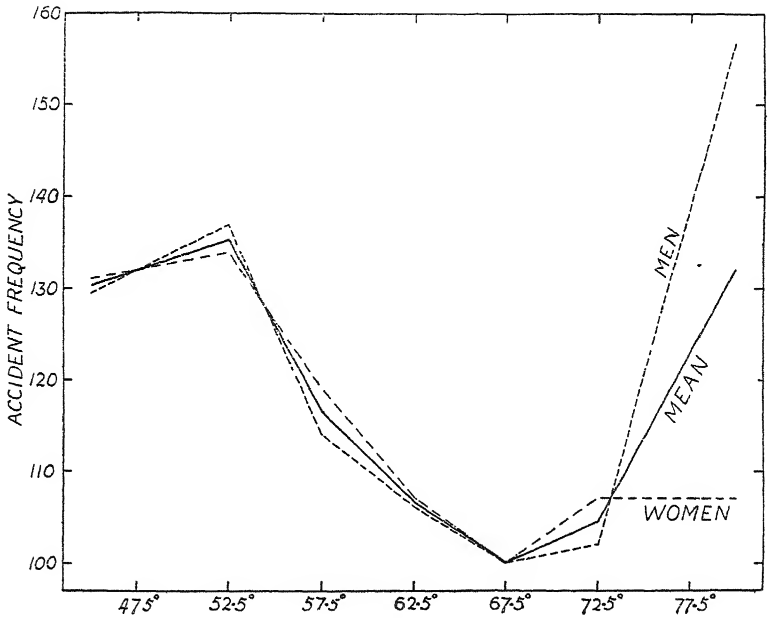

FIG 1 —Accident frequency in relation to temperature.

ranged from 50° to 61°, whilst in those with heavy machine work it was 46° to 51°. Hambly and Bedford (3) suggest a temperature of 65° to 67° for a sedentary occupation such as clicking; one of 60° to 65° for an active operation such as sole-cutting, and one of 55° to 60° for somewhat heavy operations such as lasting and edge-setting. Again, Vernon and Bedford (4) suggest a temperature of 62·5° for the continuously active but not heavy work of the potter.

Probably a temperature of about 62·5° is the most suitable

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(1) Tarbell, "New Ideas in Business," 1916, p. 12.

(2) "The Organiser," 1916, p. 196.

(3) Report No 11 of the Industrial Fatigue Research Board, 1921.

(4) Report No 18 of the Industrial Fatigue Research Board, 1922.

for ordinary machine work, and in Table III we see that such a temperature would increase accidents only 6 per cent. above the minimum.

IV. Hourly Variations in Accident Frequency.

The primary object of the present investigation was not to determine the incidence of accidents during the course of the working day, as this matter was discussed at great length in the report already referred to; but it seems worth while to put on record the results obtained at the projectile factory, as we believe them to be quite reliable, and they lend additional support to the theory of accident causation advanced in the report.

The data to be described are the fresh cuts treated at the projectile factory between October 3rd, 1917, and October 12th, 1918. They totalled 2,560 in the men, and 3,409 in the women, and their hourly incidence, during both day and night shift, is recorded in Table IV. The day shift worked from 7.15 a.m. till 5.15 p.m., and the night shift from 8 p.m. till 7.15 a.m. Owing to insufficiency of canteen accommodation the day shift workers in one of the two large shops which constituted the factory had their meal breaks at 9 to 9.30 a.m. and from 12.45 to 1.30 p.m., whilst those in the other shop had them at 9 30 to 10 a.m., and at 1.30 to 2.15 p.m. Hence it was thought best, in considering hourly incidence, to take no account of the accidents occurring between 9 and 10, and between 12.45 and 2.15 Again, it has been pointed out in the aforesaid report that it is unsafe to base conclusions on the accidents (and output) experienced during the first and last few minutes of the work spells, as the workers generally take some time to settle down to their work, and they often stop before nominal stopping time. It is best, therefore, to tabulate the accidents occurring in the first and last quarter (or half) hours of the spells separately, and this we have done in the present instance. Hence the day shift periods during which the accident frequency is considered thoroughly reliable extend only from 7.30 to 9 a.m., from 10.15 to 12.30 p.m., and from 2.30 to 5 p.m. These periods do not admit of division into full hours, so they have been, with one exception, cut up into three-quarter hour periods, but the accidents incurred during these and other periods are all expressed in the table in terms of accidents per hour (i.e., accidents occurring during the preliminary quarter-hour periods are multiplied by 4, and so on). Again, for convenience of comparison, all results are reduced to terms of 10,000 workers per week. To take a concrete instance: in the six working days of each week 10,000 men would have experienced 59 cuts altogether in the 7.30 to 8.15 a.m. period, or at the rate of 79 per hour.

As can be seen from the table, the night shift spells have been cut up on the same principle as the day shift spells. It will

be seen, also, that the time interval in which the cuts were treated are entered, not as 7.15 to 7.30 a.m., or 8 to 8.15 p.m., and so on, but as 7.21 to 7.35 and 8.6 to 8.20. This was because the nurses entered in the case books the times at which the cuts were treated by them, and not the times at which they were incurred. By making this small time allowance (viz., 5½ minutes) for the inevitable delay, the approximate time of actual occurrence of the cuts is arrived at.

TABLE IV.

Hourly Incidence of Accidents at Projectile Factory.

Time interval in which Cuts were Treated	Cuts per Hour Experienced by			Excess Power Load
	Men	Women	Men and Women (mean)	
Day Shift—				
7·21— 7·35	68	58	63	—
7·36— 8·20	**79**	**111**	**95**	93·7
8·21— 9·5	**73**	**98**	**85**	93·3
9·6 —10·5 . ..	88	118	103	—
10·6 —10 20	136	148	142	—
10·21—11·5	**95**	**119**	**107**	102·7
11·6 —11·50	**104**	**127**	**116**	108·2
11·51—12 35 . ..	**98**	**104**	**101**	106·8
12·36—12·50	71	101	86	—
12·51— 2·20	62	94	78	—
2·21— 2·35	96	96	96	—
2·36— 3·20	**89**	**109**	**99**	96 3
3·21— 4·20	**79**	**82**	**80**	101·7
4·21— 5·5	**64**	**73**	**68**	97·5
5 6 — 5·20	22	36	29	—
Night Shift—				
8·6 — 8·20	92	92	92	—
8·21— 9·20	**83**	**142**	**113**	95·2
9·21—10·5	**83**	**102**	**92**	98·0
10·6 —11·5 . ..	**64**	**94**	**79**	97·8
11·6 —11 20	24	82	53	—
11·21—12·50	57	78	67	—
12·51— 1·5 .. .	54	96	75	—
1·6 — 1·50	**64**	**109**	**87**	101·2
1·51— 2·35 . ..	**61**	**92**	**77**	103·5
2·36— 3·20	**53**	**92**	**72**	101·5
3·21— 3 35	46	66	56	—
3·36— 4·35	59	71	65	—
4·36— 4·50	56	72	64	—
4·51— 5·35	**69**	**71**	**70**	105·5
5·36— 6·20	**55**	**83**	**69**	105·0
6·21— 7·5	**50**	**58**	**54**	92·5
7·6 — 7·20	38	48	43	—

The incidence of cuts corresponded fairly well in the men and women, except during the last spell of the night shift, and the

curves in Fig. 2 show the averages between the values for the two sexes.

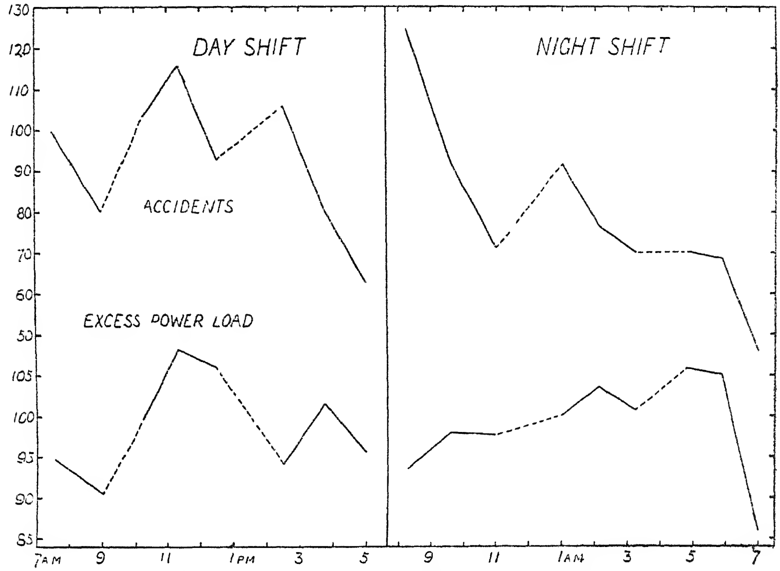

FIG. 2.—Accidents in relation to output.

The lower curves in the figure show the variations observed in the electric power load required to drive the whole of the plant at the factory during 48 consecutive hours on January 17 and 18, 1918. The power load was recorded automatically on charts, and it has been subjected to the same deduction throughout (viz., 60 per cent. of the average load) as an allowance for the power required to drive the shafting and machinery, apart from its utilisation for actual work on the shells.

It will be seen that the day shift accident curve showed a fair qualitative resemblance to the output variations, as measured by the excess power load, for both curves show low values during the first work spell, rise to a maximum in the middle of the second work spell, and fall off again in the third work spell. The correspondence is not quantitative, for the accidents varied between the extremes of 116 and 68, whilst the power load varied only from 108 to 93. It was suggested in the previous report, however, that a given increase in the hourly output of the fuse factory might well cause even five or ten times as much increase in the number of accidents, because "the speeding-up has to be done mainly by quickening the rate at which the fuse part is clamped in, or unclamped from, the lathe, and the rate at which the cutting tools are changed and brought into contact with the metal surface. Not much speeding-up of the actual cutting operations is permissible, so a given speeding-up of output means a relatively much greater speeding-up of the movements made at times when the workers are specially liable to knock their hands against the cutting tools."

In the present instance the variations in accident frequency were two to three times greater than the variation in excess power load, so it is possible that they were due entirely to varying speed of production. No close correspondence could be expected in any case, for it is unlikely that the power load variations observed on two days only would afford a close index of the average variations during the whole year for which the accidents were collected. However, it is probable that they afford a rough index, for it was shown in the previous report that power load observations made in August, 1917, gave variations in fair correspondence with the present ones. Moreover, power load observations taken at intervals of several months at the fuse factory and the 6-in. shell factory corresponded well with one another, and they likewise corresponded roughly with the variations at present under discussion, in that they showed a low output at the beginning and end of the shift, and a maximum one in the middle of it. Again, on splitting up the present accident data into four three-month periods, it was found that the relative frequency observed during each spell of the day and night shift corresponded well, both in men and women. It will be seen from Table V that accidents were invariably at a maximum during the middle spell of the day shift and during the first spell of the night shift. These accidents are the means of those incurred during the periods of full work in each spell.

TABLE V.

Cuts per Hour during each Work Spell.

Work Spell	Day Shift				Night Shift			
	Oct - Dec	Jan - March	April-June	July-Sept	Oct.-Dec.	Jan.-March	April-June	July-Sept
Men—								
1st spell.	79	95	69	61	87	86	87	44
2nd ,, ..	112	129	85	71	61	70	62	43
3rd ,, .	85	88	77	59	69	67	56	38
Women—								
1st Spell	109	127	111	72	116	133	120	86
2nd ,, .	129	140	119	79	114	116	105	55
3rd ,, ..	91	119	83	57	66	83	74	48

Passing on to the consideration of the night shift accidents, we find very different relationships from those observed by day. It will be seen from Fig. 2 that the accidents were at a maximum during the first hour of the night shift, that there was then a sharp drop, and that they finally sank to less than half their original number in the last full work period of the third spell. The power load variations, on the other hand, showed a rough resemblance to those observed by day in that they were low at the beginning and end of the shift, and at a maximum in between.

It is true that this maximum came at the beginning of the third spell of the night shift, whilst it was in the middle of the second spell of the day shift. In the previously recorded observations at the 6-in. shell factory the maximum came at the end of the first spell, so probably its position does not as a rule correspond exactly with the day shift maximum, though both day and night shift outputs agree in showing a maximum somewhere near the middle of the shift, with low values at the beginning and end.

It follows, therefore, that as far as the present evidence can show, the variations in the night shift accidents were not due to variations in speed of production. This conclusion agrees with that arrived at in the previous report, as the result of analysing a much larger body of accident data obtained at the fuse factory. What, therefore, is their causation? In the previous report great stress was laid on the psychical factor, which was stated to be "one of the most important in accident causation." It was pointed out that the day shift workers, when they started on their work in the early morning, were in a depressed and somewhat legarthic condition, but they brightened up gradually, especially after their tea and food at about 9 a.m., and they got into a more and more lively and careless state of mind as their dinner hour approached The night shift workers, on the other hand, got up several hours before coming on to work, and they often spent these hours in amusement and in having substantial meals, hence they began their work in a careless and excited state; but they gradually calmed down during the course of the night, as they had nothing but an unexhilarating breakfast and bed to look forward to. These variations in the psychical state of the workers must have produced considerable variations in accident frequency, and especially so by night, when the usual effect of output variations on accident frequency was completely swamped by them, or by some other unknown factor.

V. The Part Played by Fatigue in Accident Causation.

Most previous investigators have attributed much if not all of the hourly variation in accident frequency to fatigue, and have assumed that the gradual rise of accidents which is usually observed during both morning and afternoon work spells is a fatigue effect. The present observations show no signs of such a rise except in the middle spell of the day shift, but the observations previously recorded showed that at the fuse factory there was so rapid a rise during the five-hour morning spell of the day shift that the accidents were twice as numerous at the end of the spell as at the beginning. Even this rise was shown to be chiefly due, in the men, to some other factor or factors than fatigue, for it was found that when the men had a ten-hour day substituted for their twelve-hour day, they showed just the same rise of accidents from hour to hour. In the women, however, the shortened hours of work caused a great diminution in the rise, though it still remained

greater than in the men. For these and other reasons it was concluded that in women the accidents were distinctly influenced by fatigue, even during the ten-hour day.

The United States Public Health Service (1) has recently published a very full analysis of accidents in relation to output at a large motor car factory, where an eight-hour day was in force, and at a fuse factory, where most of the workers were on a ten-hour day. The investigators tabulated no less than 46,000 accidents altogether, and the writers of the report express the hourly accident rates in the form of accidents per unit of output. They accept the validity of the previously mentioned hypothesis that in machine operations given variations of output may induce relatively greater variations of accident frequency. Taking the number of accidents in the first hour of the working day as 100, they calculated the expected numbers in the subsequent hours on the hypothesis that accidents increased four times more rapidly than output: *e.g.*, that a five per cent. increase of output caused a 20 per cent. increase of accidents. They found that the variations of accident rate during the morning spell of work in the motor car factory (*i.e.*, the eight-hour plant) corresponded closely with hypothesis, and the same correspondence held for machine work at the fuse factory (the ten-hour plant). In the afternoon spells, however, the accident rate was in all cases greater than the theoretical. At the fuse factory the ratio of actual accidents to theoretical accidents, taken as unity, was 0·9, 1·2, 1·2, 1·0 and 3·3 in the successive hours of the spell. On splitting up the work at the fuse factory into different categories it was found that the accidents incurred from muscular work were almost always greater than the theoretical, and especially so in the afternoon spell, whilst those incurred from dexterous work and machine work showed a smaller excess.

These observations were considered to prove that the excess of accidents over the theoretical number was due to fatigue. Unfortunately the psychical factor, on which we lay so much stress, was entirely ignored by the writers of the report, and they fail to record the evidence in its favour which was at their disposal. They state* that "on the night shift at the ten-hour plant the numbers of workers employed and the accidents occurring are too small to yield conclusive data." Fortunately, Dr. A H. Ryan, who was one of the numerous investigators engaged in collecting the information on which the report is founded, has independently informed us as to the extent of the night shift accidents.† In the course of a damaging criticism on the methods and conclusions described in the report, he tabulates the accidents occurring from hour to hour, and their relationship to output in certain machine operations. These data are so important that we reproduce them in Table VI.

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(1) Public Health Bulletin No. 106. 1920.

* *op. cit.* p 125

† Ryan. *Journal of Industrial Hygiene.* Vol. II, p. 466. 1921

TABLE VI

Accidents and Ouput at U.S. Fuse Factory.

NIGHT SHIFT.					DAY SHIFT.	
Working Hours	Actual Number of Accidents incurred.	Relative Hourly Output	Relative frequency of Accidents.	Accidents per Unit of Output	Working Hours	Accidents per Unit of Output
1	152	110·9	111·6	108	1	72
2	239	118·3	175·6	159	2	88
3	222	120·5	163·1	145	3	95
4	153	120·6	112·4	100	4	100
5	155	117·3	113·8	104	5	93
6	123	102·5	90·4	95	—	—
7	52	110·2	38·2	37	6	79
8	120	110·9	88·2	85	7	99
9	127	108·5	93·2	92	8	100
10	124	106·2	91·1	92	9	105
11	111	98·8	81·6	89	10	117
12	121	74·7	88·9	128	—	—
13	70	0·5	51·4	11255	—	—

The total night shift accidents incurred numbered 1769, so they are quite sufficient to yield a reliable result. In that no correction was made for the time lost in starting and stopping work at the beginning and end of the spells, it is better to ignore the accident frequency for the first and the last time intervals of each spell (either an hour or forty minutes in duration), and confine discussion to the intermediate hours of full work. We see that accident frequency, whether reckoned in absolute measure or in terms of accidents per unit of output, was at a maximum in the second and third hours of the first spell, and then it fell away considerably in the next two hours. Unfortunately, the data are complicated by the fact that a certain (but unknown) proportion of day shift workers put in overtime work for the first three hours of night shift, and undoubtedly they were responsible for some of the accidents enumerated, though it seems improbable that they could account for all of the excess. However, it is best not to found any argument on these figures, but to consider only the thoroughly reliable ones which were obtained from the fourth hour onwards.

We see that in the fourth and fifth hours the accident frequency, per unit of output, was 100 and 104 respectively, but in the first four full hours of work in the second spell it remained nearly steady at 85 to 92. That is to say, the accident frequency of the night shift workers during most of the second spell of work was considerably smaller than that observed in the first spell, although the workers must have been fatigued by the long first spell, $5\frac{2}{3}$ hours in duration, followed as it was by a meal break lasting only 20 minutes. In the twelfth hour of the night shift the accidents

were slightly more numerous than in the eleventh hour, and their frequency, per unit of output, was considerably greater. Part of the increase was due to the fact that the workers were beginning to cease work, and were engaged in cleaning up their machines and doing other work which induced accidents having no relation to output. For these reasons the accident frequency in relation to output rose to the extraordinary value of 11,255 in the last work period (of 40 minutes duration) Still, it seems highly probable that the rise of accidents in the twelfth hour was really due in some part to fatigue. With this exception, the reduction of accidents experienced in the second spell, as compared with those in the first spell, is apparently due to the psychical factor already described. On the right side of Table VI are recorded the day shift accidents experienced in machine work. They are recorded per unit of output, and it will be seen that they show the familiar rise during each spell: *i.e.*, their incidence differs very widely from that of the night shift accidents.

At the eight hour plant described in the Bulletin the proportion of night shift workers was small, but it appears that the number of accidents incurred, or rather those considered suitable for tabulation, came to over 1,200. Yet these data, together with those of the afternoon shift, were all grouped together with those of the morning shift, and are quoted only as totals for each hour of shift. Thereby variations in frequency produced by the psychical factor are lost, and P. S. Florence, who was chiefly responsible for the statistical treatment of the material collected, admits* that this merging of the three shifts "undoubtedly had the effect of smoothing the eight hour curve to a certain extent."

Still another reason for using extreme caution in interpreting hourly variations of accident frequency has been pointed out to us by Professor E. L. Collis. He drew our attention to the fact that the labour turnover at the U.S. fuse factory was very large, and that on an average a third of all the workers had been employed for less than six months. The American investigators showed that these new-comers were much more liable to accidents than the experienced workers, for no less than 35 per cent. of all the accidents tabulated occurred during the first three months of employment, and 14 per cent. in the next three months. Hence approximately half of all the accidents were experienced by a third (*i.e.*, the inexperienced third) of the workers. Now it is known that fresh workers may take many weeks or months to attain their full output†, and it is not likely that their hourly output variations are the same as those of experienced workers. Hence, until one can obtain more homogeneous material it is impossible to argue closely as to the relationship between hourly output and accidents. Even then argument would be very difficult, for there is no measure of the degree of importance to be attached to the psychical factor.

* P S. Florence *Journal of Industrial Hygiene*. Vol II., p 479 1921.

† c f Report No. 6 of Industrial Fatigue Research Board, 1920

More satisfactory proof of the effects of fatigue on accidents is yielded by comparing the accident frequency before and after a change in the hours of work. The above-mentioned evidence at the fuse factory (described in the previous report) is a case in point, and other evidence of a like nature was described in the same report in regard to the projectile factory. Here the women were changed from a three shift to a two shift system, by means of which their weekly hours of work were increased from 44¼ hours to 54 hours, whilst the hours of the men were reduced from 63¼ hours to 54 hours: *i.e.*, the women worked 9¾ hours more than they had done previously, and the men, 9¼ hours less. In consequence of these very considerable alterations of hours, the ratio of women's accidents to men's accidents increased 39 per cent.

Further evidence was obtained at the 6-in. shell factory during the present series of observations. As already stated, the women at the factory at first put in a 10½ hour shift of work by day and by night just as the men did, or 63 hours per week when on night shift and 59 hours when on day shift (no work being done on Saturday afternoon). In February, 1918, they went on to a three shift system under which they worked a 6½ or 7½-hour shift. They put in 38, 32½ and 48 hours of actual work in successive weeks, according as they were on morning, afternoon, or night shift, the long night shift hours being due to the fact that they worked from 6 p.m. to 6 a.m. (with 1½ hours for meals) on Sunday night, but from 10 p.m. to 6 a.m. on Monday to Friday nights. On an average, therefore, the women reduced their weekly hours of work from 61 down to 39½, or by 21½ hours, whilst the men experienced no change.

The effect of the reduction of hours on accident frequency can be gathered from Table VII, which shows the number of accidents (cuts) per hour. Data relating to the January—March quarter are omitted, as the change over of shifts took a few weeks to establish, but the other data show that, whereas on an average the women had 91 per cent. as many accidents as the men during

TABLE VII.

Effect of reduction of hours of work on accidents at shell factory.

Weekly Hours of Work.	Statistical Period	Cuts per hour experienced by Men		Cuts per hour experienced by Women		Percentage of women's Accidents on Mens' Accidents.
Day Shift—						
Men and Women, 59	Oct.–Dec., 1917 .	69		58		84
Men, 59 / Women, 35¼	Apr.–June, 1918 ..	57	65	54	52	80
	July–Sept., 1918 ..	73		49		
Night Shift—						
Men and Women, 63	Oct.–Dec., 1917 ..	66		64		97
Men, 63 .. / Women, 48	Apr.–June, 1918 ..	61	63	51	48	76
	July–Sept., 1918 ..	65		44		

the 61 hour regime, they had only 78 per cent. as many during the six months period when they were on the three shift system. For convenience of comparison, the accidents of the women's morning and afternoon shifts have been averaged, and are entered in the table under "day shift." No error was introduced thereby, as it happened that the accident frequencies in these two shifts were identical. The effect of the shortened hours in reducing the women's accidents was somewhat greater in the second of the two three-month periods recorded than in the first, probably because of the gradually acquired experience of the new women taken on to form the extra shift, but in any case the great reduction in the hours of work did not effect more than a moderate reduction of accident frequency, amounting in the most extreme case (i.e., if we compare the long-hour period with the second of the short-hour periods) to 23 per cent. It looks as if the majority of the accidents experienced during the 61 hour week were due to other factors than fatigue.

VI. Summary.

The number of accidents (cuts) experienced by the workers at three munition factories was found to be greatly influenced by temperature. The temperature was registered continuously for 9 to 12 months at a projectile factory and a 6-in. shell factory by means of thermographs, and it was found that the accidents at the shell factory agreed with those previously observed at a fuse factory in reaching a minimum at 67° F. At the projectile factory the minimum was at 72°, but the combined results gave 67° as the minimum. With fall of temperature the accidents increased gradually, and to a similar extent in men and women, till at 52° they were 35 per cent. more numerous. At temperatures above 72° they increased very rapidly in men, but only to a small extent in women.

The hourly incidence of accidents experienced by the day shift at the projectile factory showed a qualitative resemblance to the output variations. They were low at first, rose to a maximum in the middle of the shift, and then fell away. The night shift accidents, however, showed no resemblance whatever to output, except during the last two hours. They were at a maximum during the first hour, then fell off sharply, and finally sank to less than half their original number. Probably this incidence was largely psychical in origin.

The influence of fatigue in causing accidents was shown at the 6-in. shell factory. When the women worked the same 61 hour week as the men, their accidents were 91 per cent. as numerous, but when their hours were reduced to $39\frac{1}{2}$ a week (those of the men being unchanged), their accidents fell to 78 per cent. of those experienced by the men.

B.—ON THE RELATION OF FATIGUE AND ACCURACY TO SPEED AND DURATION OF WORK.

BY

B. Muscio, M.A., *Investigator to the Board*

I. Introduction.

This report presents experimental data bearing upon the question whether rate of movement (speed of production) or "fatigue" is the chief factor in the hourly variations in the numbers of industrial accidents. The question is one which industrial accident statistics will of themselves in all probability never answer, since industrial accidents occur in the course of normal industrial work, and in this the two factors (rate of movement and "fatigue") cannot generally be isolated. The main object of the present report is to indicate that the problem is susceptible of solution in the laboratory. The data here presented suggest (1) the extent to which inaccuracy of movement is a function of the rate of movement alone; and (2) the extent to which inaccuracy of movement is a function of "fatigue" alone. As regards both points the data are meagre, and further research along the lines described is required; but the results given, so far as they go, are consistent and extremely definite.

II. The Experiments.

(a) *The Tests.*

Two tests of "muscular precision" involving eye-hand coordination were used in the experiments. These will be referred to as *The Aiming Test* and *The Pendulum Test.*

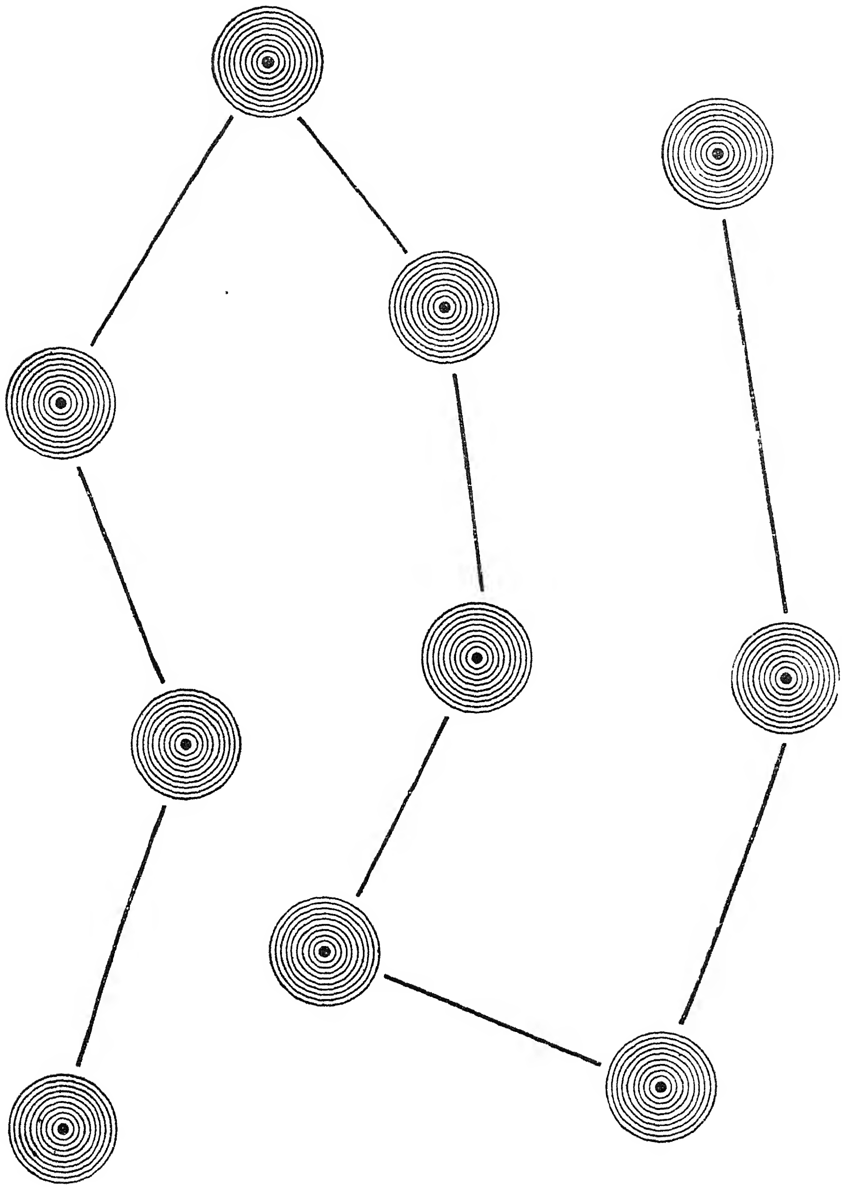
(1) *The Aiming Test.* This consisted in spearing at targets with a dissecting needle (mounted on a wooden handle) held vertically in the right hand, the arm being unsupported. The targets were printed on sheets of octavo paper, ten on a sheet, in positions similar to those of the crosses on the Whipple aiming blank (*see* G. M. Whipple's *Manual of Mental & Physical Tests*, 2nd edition, 1914, Vol. I, p. 149). Each target consisted of a block circular bull's eye two mm. in diameter, surrounded by nine consecutive circles, the distance of the circumference of the bull's eye from the

innermost circle being one mm., and the distance between the circumferences of any two successive circles being one mm. also This target was devised to facilitate scoring. The prick of the spearing needle on it can be scored accurately with the naked eye to a half mm. by means of the concentric circles.

In the present experiments the target sheets were placed on a cardboard holder lying flat on a table close in front of the subject, who carried out the test seated. The holder was kept in a fixed position on the table by drawing pins, by which also the target sheets were secured to the holder. Before starting, the subject held his needle on a small marked area between himself and the target blank; this area will be called the *starting position*. The spearing was carried out in time with the beats of a metronome. When the metronome was set going, the subject first "got the rhythm" by moving his needle up and down on the starting position in time with the metronome beats, after which he began the test, spearing at a target with one beat of the metronome and withdrawing to the starting position at the next beat, and so on continuously as long as the test lasted. Generally he went round the target blank in regular order three times—that is, he had thirty shots at the ten targets, three at each. In order to prevent confusion concerning the sequence of the "shots," a line was printed on the blank from one target to another showing the path to be followed in going once round the blank from target No. 1 to target No. 10. After reaching No. 10 the subject began again at No. 1 (until the test was finished). The average distance from the starting position to the targets was about 6 in. An illustration of a target blank is given on page 20.

This test was employed primarily to determine to what extent inaccuracy is a function of rate of movement. Different rates of movement were obtained from subjects by means of the metronome. Six rates were used in the first part of the experiments—the metronome being set at 60, 90, 120, 150, 180, and 210. At the first of these rates the subject made 60 movements—30 shots at the targets and 30 withdrawals to the starting position—in one minute; at the second he made 90 movements—45 shots and 45 withdrawals—in one minute; and so on. This test was used to get evidence concerning the second point also, namely, concerning the influence of "fatigue" alone upon inaccuracy of movement; but the labour involved in scoring the test even in its present form, when carried out for several hours continuously, was so great, that some other test seemed desirable for this purpose.

(2) *The Pendulum Test.* The "*Pursuit pendulum*" was invented by Dr. W. R. Miles, of the Carnegie Nutrition Laboratory, Boston, and is described in detail by him in *The Psychological Review*, 1920, **27**, 361-367. Essentially the apparatus is a pendulum consisting of a hollow metal tube about 140 cm long, through which water is led from a reservoir—a two-litre can—placed at about the middle of the pendulum shaft which passes through it. The stream of water (at the lower end of the shaft) flows through a



Target blank (reduced to ¼).

nozzle of 3 mm. diameter. As the pendulum swings, the subject tries to catch this water in a test tube (in these experiments held in the right hand) of diameter $\frac{5}{8}$ of an inch. The whole apparatus is fastened to a wall bracket, the foot of the pendulum shaft being about 3 ft. 6 in. from the floor, and as it swings, it passes above a zinc tank, which catches the water not caught in the test tube by the subject and acts as a supply source for the reservoir.

As used here, the test requires an experimenter to release the pendulum, to secure it again after a double swing, and to record the amount of water caught. The path travelled by the hand in one double swing of the pendulum (from one side to the other and back again) is approximately 5 ft. in length. Such a double swing will be called *one catch*. The subject stands immediately in front of the apparatus Before he starts the tests, the foot of the pendulum is at rest on a support on his left. When about to make a catch, he places the test tube against a fixture near the resting place of the foot of the pendulum shaft , this will be called the *starting position*. The experimenter, on observing that the test tube has been placed in the starting position, says " now," and about one second later releases the pendulum which the subject pursues as it swings to the right and back again, where it is once more secured No water flows from the pendulum while it is at rest. The test tube here used was made of stout glass and was graduated in c.c. It was fitted with a metal collar having a knife edge to prevent splashing. The greatest quantity of water which could be caught in one catch was found to be approximately 53 c c. The reservoir was filled after every 20 catches, so that the rate of movement of the pendulum (as between different catches—not for different parts of the one catch) may be considered absolutely constant.

In continuous work the test consisted of the following procedure. The subject, standing immediately in front of the apparatus, placed the test tube in the " starting position " upon which the experimenter said " now " and released the pendulum ; the subject pursued the pendulum and caught as much water as he could in one double swing, at the end of which the experimenter secured the pendulum again on the left; the subject raised the test tube so that the experimenter could see (and record) how much water he had caught (this involved the subject's holding the test tube towards his left on about a level with his own eyes for about two seconds); the subject emptied the test tube by inverting it over the supply tank, and thus finished " one catch." The subject then immediately placed the test tube in the starting position once more in readiness for the next catch. The whole process was continuous, and the above cycle of movements was constantly repeated in " continuous " work. After every 20th catch the subject refilled the reservoir. This necessitated rising on to a stool about 12 in. from the floor, and pouring two small jug-fuls of water (about 250 c.c. in each) into the reservoir, the water being taken from the supply tank. The " stance " of the subject was kept as constant

as possible at all times During the whole of the test the right arm, with which the test was here carried out, had no support of any kind.

The *pendulum test* involves a high degree of muscular precision. It seemed suitable for the present purpose, first because performance in it was extremely easy to score—a fact which makes possible extensive experiments with it—and secondly because it guaranteed a rate of movement almost absolutely constant (that is, the rate of movement for *one catch* was identical with that for any other) By carrying out the test for long intervals continuously, it seemed possible to determine the effects of "fatigue" upon inaccuracy of movement, separated from all effects of variations in the rate of movement (as between different catches).

(*b*) *The Subjects.*

Six subjects carried out the *aiming* test, all of them adults except one, a youth, aged 15, employed as a laboratory attendant. The five adult subjects, of whom three were men and two were women, were engaged in research work at the Cambridge Psychological Laboratory. One was the writer. The *pendulum* test was carried out (so far as the present experiments are concerned) by one subject only, the writer. Miss S. C. M. Sowton acted as experimenter for this test.

III. Results.

There will be given first the results bearing upon the question: *To what extent is the inaccuracy of movement a function of the rate of movement?* These results were obtained with the *aiming test* and, in addition to the description of this test already given, the following details should be noted.

A method had to be devised by which interferences due to practice could be eliminated. If, for instance, subjects had always started with the slowest rate used in the experiments (metronome at 60) and gone progressively to the fastest rate (metronome at 210), the inaccuracy of the faster rates might have been advantageously affected by practice at the slower rates. The following scheme was adopted in order to prevent any of the six rates having any such advantage.

At any one sitting a subject carried out the test at all six rates, making 30 shots at each rate. Five of the six subjects had six such sittings, and at each sitting the rates occurred in a different order. Six such sittings will be called *one set*. Five of the six subjects then did "one set" each. The sixth subject (a woman) did six sets. In the six sittings of any "one set," each of the six rates occurred once first, once second, once third, once fourth, once fifth, and once sixth; and to compare the effects of the different rates, the results for any one rate at one sitting were combined with the results for that rate at each of the other five sittings of the set. The order of the occurrence of the rates in each of the six sittings of a set is shown in Table I.

Table I.

Showing the order in which the six rates used with the aiming test occurred in each of the six sittings of "one set." The figures in the table indicate that the metronome was set 60, 90, *etc.*

Position of rate in Sitting.	No of Sitting.					
	1st	2nd	3rd	4th	5th.	6th
1st	60	90	120	150	180	210
2nd	90	120	150	180	210	60
3rd	120	150	180	210	60	90
4th . . .	150	180	210	60	90	120
5th	180	210	60	90	120	150
6th	210	60	90	120	150	180

The results obtained by carrying out the above scheme for six subjects ("one set" each—the *first* set of the subject who did six sets) are given on Table II. and Figs. 1 and 2. For determining the relative effect of any rate on inaccuracy, the distances in mm. from the circumference of the bull's eye of all shots made at that rate were added together, scoring having been carried out for each shot to the nearest half mm. The principle of this method for comparing the results of different rates was used also for comparing different performances at the same rate (*see below*, Tables IV, VI, and IX. It should be noted that by this method the *smaller* the "total distance" for any rate the *more accurate* is the performance of the test. The figures in Table II are mm., and were obtained by adding together the distances from the circumference of the bull's eye of 180 shots at each of the rates indicated in the table.

Table II.

Showing the results for six different rates in the aiming test for each of six subjects. Each number in the table was obtained by adding together the distances of 180 *shots, each scored to the nearest half mm., from the circumference of the bull's eye; these* 180 *shots (at each rate) being distributed over six sittings as shown in Table I.*

Subject	Rates (Metronome)						Totals.
	60	90	120	150	180	210	
A	223·5	228	326	406·5	542·5	684·5	2411 0
B	210	270·5	304	417·5	556	588·5	2346·5
C . ..	120·5	111·5	173·5	263	334 5	556	1559·0
D	223	182·5	193·5	301·5	419·5	476	1796·0
E	148·5	126	148·5	195	305	364	1287·0
F	135	163·5	194·5	224·5	321·5	367·5	1406 5
Average ..	176 8	180 3	223·3	301·3	413·1	506·1	1801

The results for the individual subjects shown in Table II are represented graphically in Fig. 1. The ordinates are the "total distances" in mm. from the circumference of the bull's eye for 180 shots, and the abscissæ are the rates (metronome).

It should be especially noted that all curves given in this report are so constructed that the higher they are the greater the inaccuracy indicated.

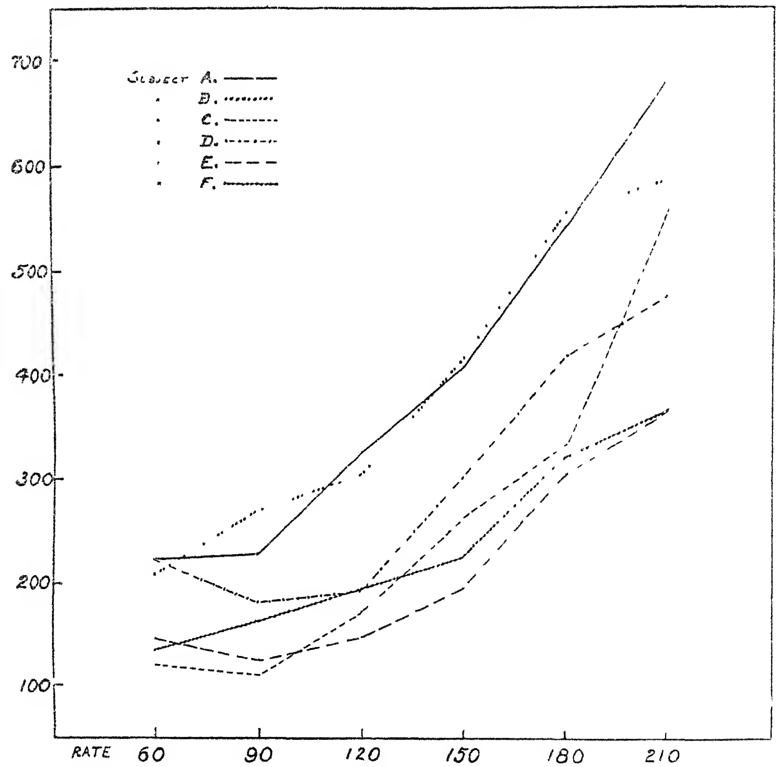


Fig. 1.

In Fig. 2 is shown the average curve obtained by combining the six individual curves of Fig. 1. The numerical data from which this average curve is constructed are given in the bottom line of Table II.

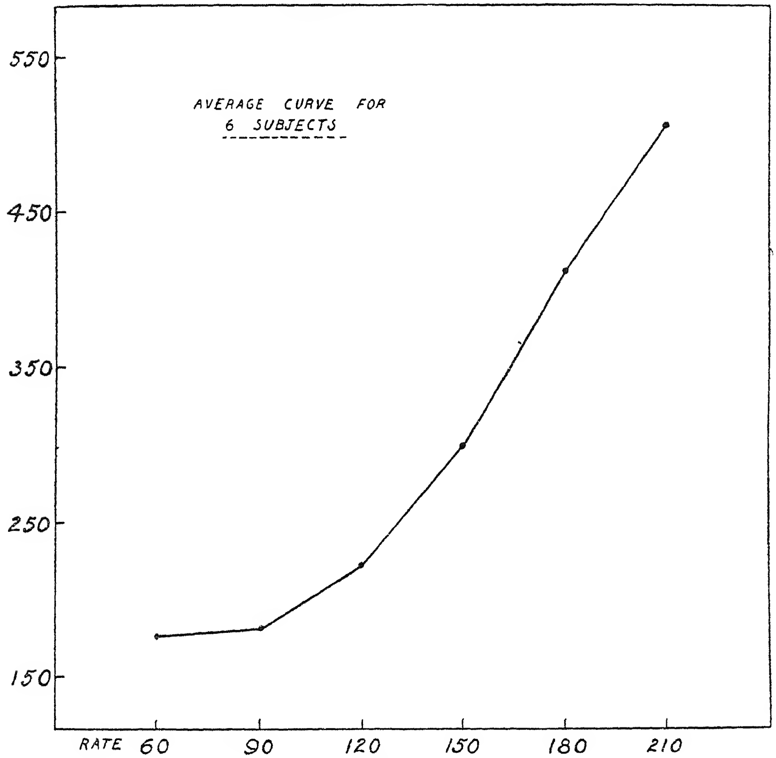


Fig. 2.

From the point of view of the present report, it may be said that the foregoing results were unaffected by practice. They were, however, obtained at an early practice stage in the test, and it may be thought that further practice might modify the results for the different rates relatively to one another (further practice would of course make the subjects more accurate at all rates; but that need not affect the results of the different rates *relatively to one another*). But *all* that further practice does is to increase accuracy at all rates; it leaves relative performance at any given rate much the same as already shown. This is clearly indicated in the results for the subject who carried out six sets of the tests. These results are given in Table III and represented graphically in Fig. 3

TABLE III.

Showing results for the six rates in the aiming test for one subject who did six sets of the test. The figures in this table were obtained in the same way as the figures in Table II.

Set	Rates (Metronome).						Totals
	60	90	120	150	180	210	
1st .	120·5	111·5	173·5	263	334·5	556	1559
2nd .	210 5	148	225	245·5	385·5	472 5	1687
3rd .	92	66·5	84·5	150·5	225	332 5	951
4th ..	155·5	81·5	122	162	254	346·5	1121
5th ..	63·5	51·5	106	134·5	247·5	308·5	911
6th .	65 5	61·5	98·5	144·5	284	384	1038
Average ..	117·8	86·8	134·9	183·3	288·4	400	1211

Fig. 3, showing graphically the results given in Table III, is constructed in the same way as Fig. 1.

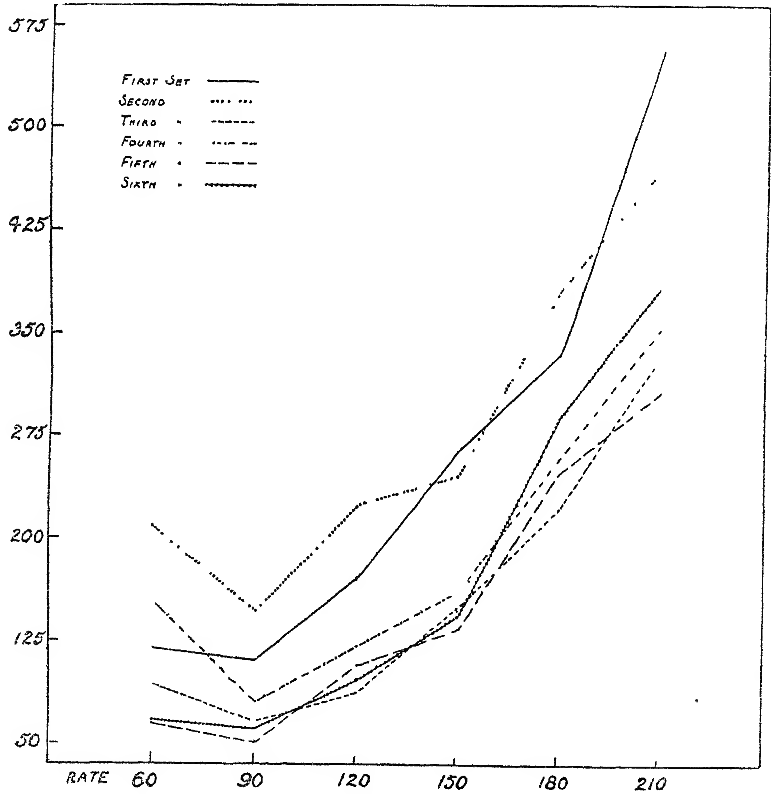


FIG. 3.

The results thus far given are all so definite and so consistent that there can be no doubt of the great increase in inaccuracy which follows upon increase in rate of movement. It will be seen,

especially from Fig. 2, that an arithmetical increase in the rate of movement does not give in general merely an arithmetical increase in inaccuracy; but that the faster the rate in operation at any time, the greater in general will be the increase in inaccuracy produced by any unit increase in rate. Whether this result belongs only to the particular movements here concerned, or is general for all movement, is a question which cannot be answered from the present data. It seems likely that the results obtained indicate a general law of all movement. But it might be anticipated that this law would hold only within a certain range of rates, which might not be the same for all movements; also that individual differences would occur here, as everywhere else. It may be noted that with one subject at least (*see* Fig. 3), the slowest rate used produced greater inaccuracy than the second slowest, at which this subject was more accurate than at any other. So far, then, as accident incidence is concerned, we can be certain that variations in speed of production will of themselves cause similar, though more pronounced, variations in the inaccuracy of movement.

The remaining results bear upon the question: *What is the effect of "fatigue" (alone) upon inaccuracy of movement?* Table IV gives results for a subject who made 60 shots in the *aiming test* at the fastest rate only (metronome at 210) once every half-hour on each of 13 days. Between the tests the subject was engaged continuously (except for the lunch period) on mental work—the calculation of correlation coefficients, etc. The test occupied little over half a minute on each occasion. The first test period on any day was at 10 a.m., and the remaining periods were as shown in Table IV. The figures in this table are the average "total distances" for 13 days in mms., the "total distance" for any one day at any one period being the sum of the distances of 60 shots from the circumference of the bull's eye (in mms.). This subject had had much practice in the *aiming* test before this part of the experiments was carried out, so that it may be accepted that his results here are entirely unaffected by practice.

TABLE IV.

Showing the results for one subject who made 60 shots in the aiming tests, with the metronome at 210, at half-hour intervals on each of 13 (mental) work days. The score for any one performance of the test was obtained by adding together the distance (in mms.) from the circumference of the bull's eye of the 60 shots made in that performance. The "average scores" in the table are the averages for the stated times of 13 such performances, one on each of 13 days s.d. = standard deviation (in mms.).

Time of Test	10 a.m	10 30 a m.	11 a m	11·30 a.m.	12 noon	12 30 p m	1 p.m	2 30 p m	3 p.m	3 30 p m	4 p m	4 30 p m	5 p m
Average Score ..	113 7	97 9	103 6	98 0	102 5	93 2	98 5	116 4	108 0	101 1	99 7	100 2	98 6
s d	10 00	14 76	10 08	11 23	12 86	10 58	13 38	13 62	13 54	9 16	12 64	14 41	14 32

The results (average scores) of Table IV are shown graphically in Fig. 4, the general construction of which is similar to that of Figs. 1, 2 and 3.

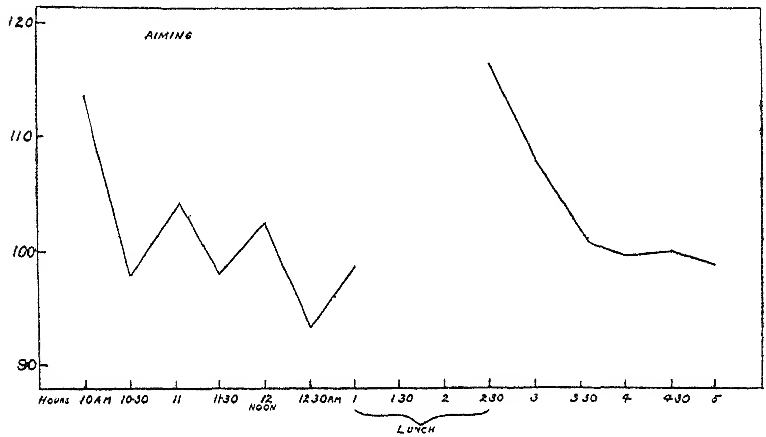


FIG. 4.

Table V shows the results for the *pendulum* test similar to those given in Table IV for the *aiming* test, though the times when the two tests were performed are not entirely the same. The *pendulum* test was carried out by the subject (the writer) until practice effects were inappreciable, before the experiments yielding the results now to be given were started; so that here (and in all later *pendulum* test results) it may be accepted that the *pendulum* test data are *absolutely* unaffected by practice. Miles states that (as regards his test) "the chief part of the rise due to practise can be quickly worked off by 200 or 300 catches" (*ibid.* 371), and gives results supporting this statement. It may indicate how free the present data are from interferences due to practice, if it is stated that the writer made approximately 1,000 catches with the *pendulum* test before carrying out any of the experiments of which results are given in this report.

The results given in Table V are for six days. At each of the times stated in the table, 20 catches were made, occupying about $3\frac{1}{2}$ minutes. Between the test periods the subject was engaged continuously on mental work connected with research. For comparative purposes the total number of c.c. of water caught in five catches is used as unit. Hence, on each performance of the test, the results were resolved into four units; and as the procedure was carried out on six days, the average figures in the table are the averages for 24 units at the stated times. The afternoon results, however, are for three days only.

TABLE V.

Showing results for one subject who made 20 catches with the pendulum test at half-hour intervals on each of six (mental) work days (three afternoons). The average figures in this table are averages for units of five catches, as explained above:

Time of Test	9 a m	9 30 a m	10 a m	10 30 a m	11 a m	11 30 a m	12 noon	12 30 p m	1 p m	2 30 p m	3 p m	3 30 p m	4 p m
Average No. of c c caught per 5 catches	213	216	217	219	225	225	224	226	226	217	219	226	220
s d (in c c) ..	21 36	12 54	13 15	14 60	14 57	9 75	12 61	11 90	15 97	13 64	10 71	10·57	10 63

The average results given in Table V are shown graphically in Fig. 5. The ordinates are the quantities of water (in c.c.) caught in units of five catches.

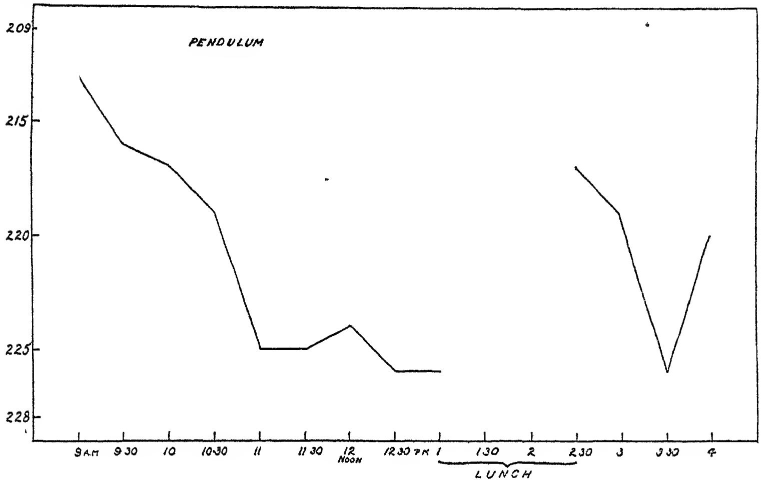


FIG. 5.

It will be seen that the results for the *aiming* and *pendulum* tests given in Tables IV and V (and the corresponding Figs.) are in general agreement. They show a general increase in *accuracy*, not a general increase in *inaccuracy*, over the greater part of the morning, and, with the exception of the 4 p.m. test period for the *pendulum* test (see Fig. 5), a similar feature characterises the afternoon results. All these results, however, were obtained when the tests were interpolated in mental work; and if "fatigue" were specific, the functions involved in the performance of the tests would not have been "fatigued" at all by the mental work. The question arises, what would be the character of the results if the tests themselves were carried out continuously over long periods?

Table VI gives results for one subject for continuous work lasting about two hours and twenty minutes at the *aiming* test. Practice improvement for this subject in this test was entirely eliminated before these results were obtained, the previous

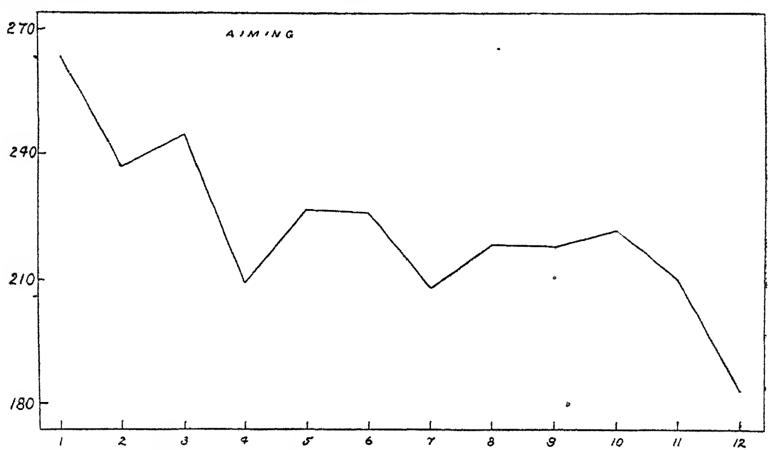
practice having amounted to 720 shots at each of the six rates (60, 90, 120, 150, 180, 210). In the present experiment, the subject used five rates only (90-210), the 60 rate being excluded because it was considered "too slow to be pleasant." The procedure during the work was as follows: The subject first made 30 shots at each of the five rates in the order 90, 120, 150, 180, 210, and then 30 shots in the reverse order (210, 180, 150, 120, 90), (30 shots involve 30 withdrawals to the starting position). The 300 shots thus made were considered a unit for comparative purposes, the distances of all 300 shots (in mms) from the circumference of the bull's eye being added together, which gave the "total distance" for each 300 shots, at the defined rates, from the circumference of the bull's eye. The whole period of continuous work contained 12 such units, which are referred to in Table VI as *periods*. Each "period," then, represented 300 shots, and about 12 minutes of time. The work began at 10 a.m.

TABLE VI.

Showing the results for continuous work for one subject in the aiming test at rates 90, 120, 150, 180, 210. *The scoring is the same in principle as that used earlier for this test. The figure in the table for any rate and period is the "total distance" of* 60 *shots from the circumference of the bull's-eye at that rate and period, the* 60 *shots being distributed as described above.*

Rate (Metronome).	PERIODS. (300 shots in each period, 60 at each of the 5 rates used)											
	1st.	2nd	3rd	4th.	5th.	6th.	7th	8th.	9th.	10th	11th	12th
90 .. .	31	21	30	27	30	24	25	24 5	23 5	22	25	22
120	26	29	25 5	27 5	27	25 5	24	23 5	21	18 5	33	20
150 .	42	45	30 5	34	34	35 5	35	35	26	33 5	29	31
180	66	67 5	64	59	55	71	55	57	62 5	62	59	47
210 .	99	74 5	95	62	81	70	69	78 5	85	86	64	63
Total .	264	237	245	209 5	227	226	208	218 5	218	222	210	183

Graphical representation of the *total* results for the different periods, as shown in the bottom line of Table VI, is given in Fig. 6.



The construction of this figure is similar to that of earlier figures for the *aiming* test, except that the abscissœ represent "periods."

Results for continuous work (for one subject) with the *pendulum* test are given in Tables VII and VIII. The results in Table VII were obtained in a period of $2\frac{1}{2}$ hours continuous work with the test, during which 900 catches were made; while the results in Table VIII were obtained in a period of $3\frac{1}{2}$ hours continuous work with the test, during which 1,300 catches were made. In both cases, the whole work period has been divided into "100 catch" periods for comparative purposes, though in each "100 catch" period the result is given, as before, as an average for each five catches: that is, for each such period, the "average" figure given in Tables VII and VIII indicates the average number of c.c. of water caught in 20 successive units of five catches each. In the shorter experiment ($2\frac{1}{2}$ hours) there was a rest interval of about one minute after each "100 catch" period, while in the longer experiment ($3\frac{1}{2}$ hours) the work was absolutely continuous. The actual movement of the pendulum was of course constant throughout (the reservoir was refilled by the subject, as explained above, after each 20th catch); and the total time required for each 100 catches was approximately constant at 16 minutes.

TABLE VII.

Showing results obtained by one subject working continuously for $2\frac{1}{2}$ hours at the pendulum test. Each "period" is the time taken to make 100 catches (approximately 16 minutes). The "average" numbers in the table are the average numbers of c c. of water caught per unit of five catches, of which units there were 20 in each period.

PERIOD (100 catches).	1st	2nd	3rd	4th.	5th	6th.	7th	8th.	9th
Average No of c c caught per 5 catches	224	223	232	231	232	234	236	235	240
S D (in c c)	10 91	10 82	13 72	14 58	11 55	11 27	8·86	11 58	6 97

TABLE VIII.

Showing results obtained by one subject working continuously for $3\frac{1}{2}$ hours at the pendulum test. The explanation of this table is the same as that of Table VII.

PERIOD (100 catches)	1st	2nd	3rd	4th.	5th	6th	7th	8th	9th	10th.	11th	12th.	13th.
Average No. of c c. caught per 5 catches	231	234	234	235	239	244	242	240	244	242	245	242	242
S D. (in c c) ..	9 64	8 94	9 09	7 81	8 41	6 75	8 00	10 44	9 64	8 63	9·30	8 63	9·49

Graphical representation of the average results of Tables VII and VIII are given in Figs. 7 and 8. The construction of these figures is similar to that of Fig. 5.

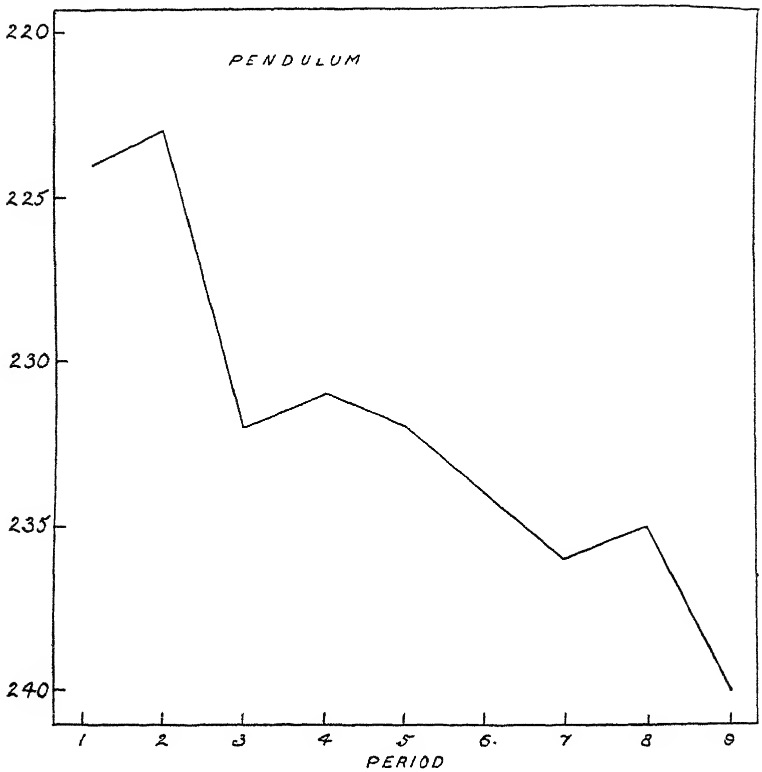


FIG 7.

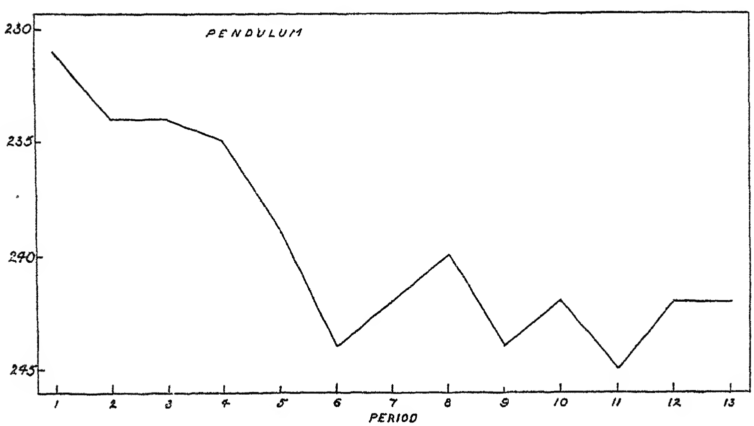


FIG. 8.

The results given in Tables VI, VII and VIII for continuous work at a constant rate with the *aiming* and *pendulum* tests are in general agreement. Their most prominent feature—and a somewhat surprising feature—is a tendency for the *accuracy* of the performance, not its *inaccuracy*, to increase over the whole work period. For the period of 2 hours and 20 minutes continuous work with the *aiming* test the accuracy was easily greatest at the very end of the period (*see* Fig. 6), and the same is true for the period of 2½ hours continuous work at the *pendulum* test (*see* Fig. 7). In neither case is the final achievement in accuracy a mere "spurt"; on the contrary, and especially in the latter case, the performance in the test tends constantly to improve in accuracy as the work proceeds. The *pendulum* test results for the longest continuous period of all, 3½ hours, show much the same character; the most accurate performance of all is made about three hours after starting. In none of these results is there the slightest tendency shown for *inaccuracy* to increase as the work proceeds.

All the above results, relative to the effects of "fatigue" alone on inaccuracy, are wholly unlike what we should expect if "fatigue" were the principal factor in the hourly variations in the number of industrial accidents. No inaccuracy curve at all approximating to the usual industrial accident curve for the morning hours was obtained in the present experiments from "fatigue" alone. The only way in which it seemed possible to obtain experimentally an inaccuracy curve similar in general form to the industrial accident curve for the morning hours was by introducing successive increases in rate of movement into continuous work. A typical result obtained in this way is shown in Table IX. A subject worked continuously at the *Aiming* test for a period of two hours, during which 137 target blanks were used, 30 shots being made on each In order to compare results for different parts of this continuous work period, the shots made on each successive five blanks have been combined; otherwise, the scoring is similar to that used earlier for this test. The subject started with the metronome at 150, and did 35 blanks at that rate; then the rate was changed successively as follows: 155, 160, 165, 170, 175, 180, 175. Fifteen target blanks were used at each rate except the last, at which ten were used. The work started at 10.30 a.m.

Table IX.

Showing the results for one subject working continuously for two hours at the aiming test at successively increasing rates of movement. The numbers in the column headed " score " are the " total distances " in mm. from the circumference of the bull's eye of the 150 *shots made on each set of five target blanks.*

Successive 5 Target Blanks—150 Shots.	Rate—Metronome	Score.
1st	150	84·5
2nd	,,	81
3rd	,,	72·5
4th	,,	80·5
5th	,,	73
6th	,,	65
7th	,,	62
8th	155	68 5
9th	,,	66·5
10th	,,	56 5
11th	160	93
12th	,,	74
13th	,,	89
14th	165	80·5
15th	,,	105
16th	,,	104
17th	170	100·5
18th	,,	113
19th	,,	100
20th	175	114·5
21st	,,	122·5
22nd	,,	91
23rd	180	97·5
24th	,,	110·5
25th	,,	128·5
26th	175	109
27th	,,	110·5

Graphical representation of the results given in Table IX is shown in Fig. 9. This figure is constructed similarly to earlier Figs. for the *aiming* test, except that the abscissæ show the successive five target blanks and the metronome rate for each.

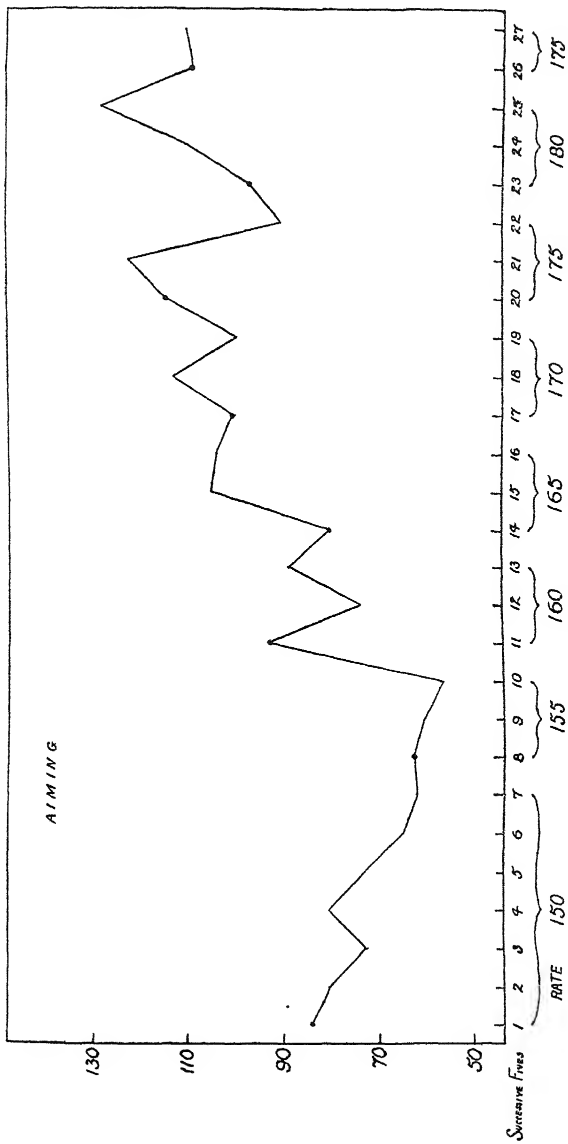


Fig. 9.

It will be seen that in these last results there is at first a gradual improvement in accuracy of performance, and that this continues so long as the rate is not increased, and even *after* the first increase from 150 to 155 (*see* Fig. 9). This agrees with the results given earlier for continuous work both with the *aiming* and

with the *pendulum* tests. With the change in rate from 155 to 160 the inaccuracy increases, and thereafter inaccuracy tends to increase with increase in rate. It would therefore appear that rate of movement must be gradually increased from the very beginning of a period of continuous work if there is to be obtained experimentally an inaccuracy curve similar to the ordinary industrial accident curve for the morning hours.

IV. Summary and Conclusion.

Data are given in this report showing that (1) an increase in rate of movement (for certain rates used) causes an increase in the inaccuracy of movement, and that the faster the rate in operation at any time, the greater in general is the increase in inaccuracy produced by any unit increase in rate, (2) continuous work for several hours (in one case for $3\frac{1}{2}$ hours) with tests of motor precision fails to show a gradual increase in inaccuracy but the very reverse, the resulting inaccuracy curve being almost the exact opposite of the typical industrial accident curve for the morning hours; (3) a curve for inaccuracy of movement, broadly similar to the typical industrial accident curve for the morning hours, can be experimentally obtained by gradually increasing the rate of movement in a morning period of continuous work with motor precision tests.

In view of what is known concerning hourly variations in speed of production, the conclusion suggested by these results is that the principal factor in the hourly variations in the number of industrial accidents is *not* "fatigue," but *rate of work* There *may* be hours of the work-day for which this conclusion is not true, and the question whether this is so or not is highly important; but the conclusion seems true for the morning hours at least.

It is suggested that further experimental data should be collected bearing upon the present question. Results should be obtained from a greater number of subjects than took part in the present experiments; longer periods of continuous work should be used, and tests (of muscular accuracy) involving a greater expenditure of energy than the *aiming* and *pendulum* tests, should be employed Modification of the present experiments in any of these ways might yield results more or less different from those given in the present report.

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PAPERS BASED ON RESULTS OBTAINED FOR THE BOARD AND PUBLISHED IN SCIENTIFIC JOURNALS.

WYATT, S., and WESTON, H. C. (1920): A Fatigue Test under Industrial Conditions.—*Brit. Journ. Psych*, **10**, Part 4.

MUSCIO, B. (1920). Fluctuations in Mental Efficiency.—*Ibid*, **10**, Part 4.

MUSCIO, B (1921) Is a Fatigue Test Possible?—*Ibid*, **12**, Part 1.

MUSCIO, B (1921) Feeling Tone in Industry.—*Ibid.*, **12**, Part 2.

STURT, M. (1922): A Comparison of Speed with Accuracy in the Learning Process—*Ibid.*, **12**, Part 3.

HILL, L, VERNON, H. M., and HARGOOD-ASH, D. (1922): The Kata-Thermometer as a Measure of Ventilation.—*Proc. Roy. Soc.* B. **93**, 198.

RUSHER, E. A. (1922). The Statistics of Industrial Morbidity in Great Britain—*Jr. Roy Stat. Soc.*, **85**, 1.

FARMER, E. (1922): Time and Motion Study.—*Journ. Ind Hyg*, **4**, 4.

MUSCIO, B. (1922): Motor Capacity with Special reference to Vocational Guidance—*Brit. Journ Psych*, **13**, 2.

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To suggest problems for investigation, and to advise upon or carry out schemes of research referred to them from time to time by the Medical Research Council, undertaken to promote better knowledge of the relations of hours of labour and of other conditions of employment, including methods of work, to functions of the human body, having regard both to the preservation of health among the workers and to industrial efficiency; and to take steps to secure the co-operation of industries in the fullest practical application of the results of this research work to the needs of industry.

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PREFACE.

The Board in one of their previous Reports* have emphasised the special difficulty in their work which arises from the large number of variables affecting human efficiency and fatigue in industry under working conditions and from the frequent impossibility of isolating any given factor and attributing to it its own effect.

One possible way of reducing this difficulty is to make a comparative study of the process in two or more industries having every feature except one in common, but differentiated sharply in respect of the influence of this one factor. By these means, it becomes possible theoretically to isolate this factor, or at any rate to gain some knowledge of its operation by an investigation of its maximum and minimum effects.

It has, for example, long been known that an atmosphere which is both hot and humid is physiologically unfavourable to the worker, and this fact has been officially recognised in the inquiries undertaken in,† and the regulations framed for,‡ the industries in which these conditions prevail. Hitherto, however, little attempt has been made to express this effect in terms of lowered efficiency.

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* Second Annual Report of the Industrial Fatigue Research Board to 30th September, 1921 (*H M Stationery Office*)

† Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds First Report, Cd 4484, 1909 Second Report, Cd. 5566, 1911. Departmental Committee on Humidity and Ventilation in Flax Spinning and Linen Weaving. Report Cd. 7433, 1911.

‡ The statutory requirements at present in force may be summarised as follows :—

Nature of Requirement.	Process or Industry.	Authority.
Prevention of escape of steam into the atmosphere	Wet-spinning of flax	1 Edw 7, c.22, s 76 (re-enacted from the Factory Act of 1844).
Limitation of permissible atmospheric humidity	(*a*) Worsted spinning by the French process	S R. & O 1898, No. 1114, made under 1 Edw 7, c 22, s.96
	(*b*) Spinning and weaving of flax	Regulations (S R. & O. 1906, No. 177).
	(*c*) Spinning and weaving of hemp and jute.	Regulations (S.R. & O. 1907, No. 660).
Limitation of permissible atmospheric humidity and specification of certain wet-bulb temperatures above which humidification is prohibited	Cotton weaving.	Regulations for Cotton Cloth Factories (S R. & O. 1911, No. 1259), made in pursuance of 1 & 2 Geo. 5, c.21
Limitation of wet-bulb temperature in certain processes	Manufacture and decoration of pottery	Regulations (S.R. & O. 1913, No. 2).

(6684) Wt.6084/359/256 1000 12/22 Harrow G.36

An opportunity of this kind occurs in the textile trades. In the manufacture of textiles the successive processes have a close family likeness and differ in detail rather than principle. The environmental conditions, however, sometimes show great variations according to the class of fibre concerned. In the process of plain weaving, for instance, certain kinds of yarn on account either of their coarseness (as in the case of jute) or of their natural flexibility (as in the case of silk) can be treated without any special provision in regard to atmospheric conditions. Other kinds, again, such as certain types of cotton yarn, can only be satisfactorily woven when exposed to air above a certain temperature and containing a certain amount of moisture, which is generally artificially introduced for the purpose. Finally, extreme demands are made in the weaving of a certain class of fine linen material known as cambric, the intractability of the yarns used calling for the maximum degree of humidity combined with the highest possible temperature. In other respects, *i.e.*, from the manipulative and mechanical points of view, the process of plain weaving is practically identical in all the textile industries.

Weaving processes, therefore, may be divided into three categories, according to whether the yarn requires no addition, a limited addition, or a large addition to the natural humidity of the air. The Board have instituted inquiry into typical examples of each of these three classes in the hope that some light would be thrown on the question as to how far the environment of the worker when it becomes physiologically unfavourable is reflected in lowered efficiency, as indicated by a reduction in output.

In the case of the first class, of which silk weaving was the type selected, the investigation* was carried out in winter and the conditions accordingly were unfavourable for exploring the relationship of temperature and humidity to human efficiency. Within the limits of the investigation a rise of temperature appeared to have a favourable effect on production (probably owing to physical causes), whilst the small changes recorded in the humidity of the air gave negative results.

More definite information has been obtained in the case of cotton weaving, a type of the second class indicated above. Wyatt,† for instance, has shown that the time taken by the weaver to deal with each breakage tends to increase as the temperature and humidity rise, and that when the effect of the mechanical factor in production is eliminated by calculation, a distinct fatigue effect is disclosed.

In the present report, dealing with the more extreme conditions prevalent in cambric weaving, the evidence in the

---

* Elton, P. M (1920) : A Study of output in Silk weaving during the winter months. (*Ind. Fat. Res. Bd. Report* No. 9.)

† Wyatt, S (1922) : Variations in efficiency in cotton weaving. (*Ind Fat. Res Bd Report* No. 23.)

same direction is still more conclusive. As has been shown in a previous inquiry, production is *physically* stimulated by a high temperature and a high degree of humidity, so that apart from the human factor, efficiency should increase *pari passu* with temperature and humidity. In the present report, this is shown to hold good below a certain limit of temperature, but when the wet-bulb temperature reaches 73°F., the efficiency falls off as the working day progresses.

In both instances, then, there are clear indications that at a certain stage the beneficial physical effects produced on the yarn are more than counterbalanced by the fatigue resulting from the unfavourable physiological conditions. It is also of interest to note that the critical temperature at which this effect becomes apparent coincides almost exactly with that indicated by Haldane, L. Hill and others as the limit beyond which working disability begins. In another Report* of the Board some suggestions are made as to means of overcoming or at least of alleviating this effect.

A further point brought out in the present report is the relative disadvantage of artificial light compared with daylight. Under the former, production falls off by approximately 11 per cent., which agrees closely with the figures of 10 per cent found by Elton in silk-weaving, a similarly fine process†, and of 5 per cent by Wyatt in certain types of cotton weaving,‡ in which the yarns used are much coarser.

The Board desire to acknowledge their indebtedness to Messrs. Spence Bryson & Co., Ltd., and to the Portadown Weaving Co., Ltd., of Portadown, Co. Armagh, through whose courtesy facilities were afforded for this investigation.

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* WYATT, S (1922): Atmospheric Conditions in Cotton Weaving. (*Ind. Fat. Res Board Report* No. 21)

† ELTON, P M : *loc. cit.*

‡ WYATT, S : *loc cit* (Rep 23).

A STUDY OF EFFICIENCY IN FINE LINEN WEAVING.

By H. C. WESTON, M.J.Inst.E.,
Investigator to the Board.

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INTRODUCTION.

THE investigation which is the subject of the present report was carried out in two linen-weaving sheds situated in the North of Ireland. It was undertaken largely for the purpose of enabling a comparison to be made between the conditions of work in linen sheds and the efficiency of linen weavers, and the corresponding conditions of work and efficiency in cotton-weaving sheds.

The general depression of trade, which necessitated the adoption of short time in cotton-weaving sheds towards the close of the cotton investigation, became acute some months earlier in the fine linen trade, with the result that short time was worked at the commencement of the linen inquiry and continued throughout the whole period of the investigation.

The investigation extended over a period of approximately six months, from July, 1920, to January, 1921, and therefore included the summer and a portion of the winter months. The summer months, however, were abnormally wet and cold, and, principally for this reason, the temperature of the sheds was seldom excessive, and the difference between the summer and winter conditions in this respect was accordingly unusually small.

The North of Ireland is very similar to Lancashire in climatic conditions, but is slightly cooler in summer and slightly warmer

in winter; whilst the rainfall is about 8 per cent. greater, the average yearly humidity differing, however, very little.*

The flax fibre being less elastic than cotton, the yarn is more liable to break in weaving, so that when fine yarns are used, as in cambric weaving, greater humidity is required, the difference between the wet and dry bulbs seldom exceeding two degrees. In spite of this, however, the fine linen weaver has to deal with a larger number of breakages and probably has less "passive" working time than the average cotton cloth weaver, and is able to attend to only two looms.

Method of Investigation.

The method of investigation adopted was that of recording the output from each of forty looms, most of them operated by women weavers, in each shed by means of pick-counters fitted to each of the looms under observation, which enabled the output of each loom to be determined at any time to the nearest hundred picks † The pick-counters were read every hour throughout the day, except at the beginning of the morning and afternoon spells, when readings were taken after the first half-hour's work.

In the cotton investigation arrangements were made for all the operatives under observation in any particular shed to weave the same kind of cloth during the whole period of investigation, so that a comparison could be made between the efficiency of one weaver and another. In the linen inquiry this was impracticable, and the records obtained are, therefore, unsuitable for the study of the comparative efficiency of individual weavers.

In addition to records of output, hourly readings were taken of the wet and dry bulb temperatures in the vicinity of the looms by means of hygrometers placed in suitable positions, and during the winter months the time during which artificial light was used in the sheds was recorded each day.

The two sheds in which this investigation was carried out will be distinguished throughout the report as Shed A and Shed B.

Nature of the Weaving Process.

The process of cloth weaving consists in interlacing threads of yarn in such a manner as to form a fabric or texture. In order to do this in the most effective way, and thus to form the strongest fabric, there must be two series of threads which, when interlaced, lie at right angles to one another, and this interlacing is effected

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* Report of the Departmental Committee on Humidity and Ventilation in Flax Mills and Linen Factories. Cd. 7433. pp. 51, 52.

† A "pick" or "shot," as it is usually termed in the linen trade, is the weft thread left in the warp by the shuttle as it is thrown from one side of the loom to the other The pick-counter is attached to the tappet-shaft of the loom which makes one revolution to every pick.

by means of the loom. The loom must be provided with means for continually feeding forward the warp* and for shedding† the latter, together with means for passing the weft‡ through the shed and for beating up § the cloth thus formed. The simplest form of cloth (with the weaving of which the present report is concerned) is that in which the weft threads pass over and under alternate warp threads so as to form what is ordinarily known as "plain" cloth.

The part the weaver plays in the process of converting yarn into cloth consists in watching the loom, attending to yarn breakages whenever they occur, replenishing the weft in the shuttle, and finally taking off the finished cloth. Thus described, the weaver's task appears to be a simple one, and it would be even simpler if the warp and weft were never liable to break, because it would then only be necessary to replenish the weft in the shuttle when required and to remove the cloth from the loom when it was woven. Unfortunately for the weaver, however, the warp breaks very frequently, and when it does so the task of repairing it is by no means always easy. A weaver's beam contains, as a rule, many thousands of yards of yarn, and a single beam may be made up with yarn spun by several spinners under different conditions, and perhaps from different crops of flax, so that it is hardly to be expected that the quality of the yarn on a beam will be uniform throughout the whole of its length. In addition, the warp may be broken many times in the process of beaming, and if it is badly repaired it will probably break again in the course of its passage through the loom, whilst the dressing applied to the beam before it goes to the loom may be uneven and patchy, with the result that some parts of the yarn will be less able than others to stand the strain of weaving without breaking. The weft yarn used in weaving a piece of cloth may also vary considerably in quality.

When the weft breaks the loom is stopped automatically by means of what is known as the "weft-fork" mechanism, and this also occurs when the whole of the weft in the shuttle has been used. The weaver has then only to replace the shuttle by

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* The warp contains all the threads running lengthwise of the cloth. These threads are wound on to a large spool, called the "beam," after they have been "dressed" with a preparation which binds the fibres of the yarn together and thus enables it to withstand the strain imposed upon it during its passage through the loom.

† "Shedding" is the action of raising and depressing alternate warp threads so that a "V" shaped space is left between them through which the shuttle passes.

‡ The weft consists of all the threads running widthwise of the cloth. Weft yarn is wound on "pirns," which are then placed in the shuttle, the latter being thrown from side to side of the loom, through the shed, by means of "picking-sticks."

§ "Beating up" consists of pressing each "shot" closely against the preceding shot by means of a reed.

one containing a new pirn, and perhaps to pick out a broken shot, when the loom can be restarted. In the case of warp breakages, however, the loom has to be stopped by the weaver, and, unless he notices the breakage immediately it occurs (this is by no means a simple matter if very fine cloth is being woven, even if constant attention is paid to the loom), many shots may be made before the loom can be stopped, and these have then to be "ripped" out until the point of breakage is reached, thus increasing the work of the weaver and wasting much of his time. Some weavers occasionally look at the warp behind the "heddles"* in order to see whether any bad piecings, ravels, or other possible obstructions to the passage of the yarn through the heddle eyes, or the reed, are coming up, and by so doing they are able to rectify these faults in time to prevent a breakage of the yarn, often without the necessity for stopping the loom.

When a warp thread, or "end" as it is usually called, breaks, it may do so at any point in its length, from the cloth-fell† to the beam, and the task of piecing it up may be complicated by the fact that in breaking it has become crossed, *i.e.*, entangled with several adjacent threads, so that it has to be disentangled and traced to its proper place in the warp before being tied. If several ends break at the same time, some weavers, owing to their anxiety to get the loom restarted as soon as possible, do not trouble to straighten their broken ends thoroughly before tying them, thinking that they may find an opportunity of doing so later on, perhaps while the loom is running. This is, of course, a mistaken policy, and is usually responsible for far more trouble than it saves, since, if the anticipated opportunity does not occur at the right moment a crossed beam is sure to result in many otherwise avoidable breakages.

A number of good weavers at Shed "A" were questioned as to their methods of work with a view to determining whether they relied upon any particular practice as being, in their opinion, the secret of success. While these weavers agreed that the first essential of efficient weaving is close attention to the work, most of them had their own individual method of performing some of the necessary operations to which they attached special importance.

Their methods were observed in the shed, and subsequently evaluated with the aid of facts of experience known to the management. As a result the instructions given on p. 5 were prepared as a statement of the best method of work.

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* The heddles are frames containing a series of cords each provided with a central eye through which an individual warp thread is passed. The heddles are raised and depressed, by means of tappets and levers, and thus raise and depress the warp to form the shed. In cambric weaving four heddles are generally used

† The cloth-fell is the line at which the warp ends and the woven cloth begins.

FOURTEEN POINTS FOR THE YOUNG WEAVER.

1. Concentrate on the work.

2. Spare no pains to ensure that broken ends are put in STRAIGHT. The time spent will be well repaid.

3. Never take a lap off the beam when tying in yarn.

4. Scan the cloth frequently, so that "ends out" and "floats" don't get a chance.

5. Where there is close attention there is little ripping out, but when it IS necessary, don't forget the other loom, if there is one, or your troubles will increase.

6. The habit of damping the selvedges before starting up after a rip does no good and often much harm

7. The selvedges are often saved after ripping by letting back the cloth and stretching it as wide as possible beyond the temples, which will hold it out when taken up again and prevent undue strain when restarting.

8. Don't apply too much force to the handwheel when putting back the yarn beam after a rip. Much yarn is broken out on restarting through being overstrained in this way.

9. See that troubles such as bad piecings and ravellings are got rid of before they reach the heddles.

10. Ends that break behind the back shell should go round the "whip roll" when being tied on. Short cuts don't pay.

11. Watch the pirn that is nearly empty. When there is only a yard or two left, stop the loom so that the shuttle is ready to leave the box Everything is then right for reshuttling and starting. Besides the time saved, there is no broken shot.

12. All breakages are not caused by bad yarn, as you will find if you try to weave with two shuttles at once. Some are caused by :—

(*a*) A rough shuttle or blunt tip.
(*b*) Pirn too high in the shuttle
(*c*) Bad sheds.
(*d*) Loom picking too late or too early.
(*e*) Warp too tight or too slack.

In these and in many other cases, the tenter* can help. It is his job.

13. Don't leave one loom idle in order to get a cut out of the other for next pay. It is a loss in the end.

14. Don't neglect defective eyesight, but take only the advice of those qualified to give it.

* The "tenter" in a linen shed is equivalent to the "tackler" or "overlooker" in a cotton shed.

Certain factors under the control of the tenter affect the efficiency of a weaver, and a low efficiency may sometimes be due to the tenter's inattention or incompetence. This, however, is not likely to occur often, as a considerable part of the tenter's earnings is determined by the earnings of the weavers under his control, and would, therefore, be directly affected by any action or inaction on his part which tended to reduce the weavers' efficiency. If the tenter is busy, however, and is therefore unable to give immediate attention to a weaver's loom, the weaver will sometimes attempt to make the necessary adjustment himself, not always, however, without making matters worse instead of better.

The adjustment of the heddles, which is rendered necessary by changes in the condition of the atmosphere which affects the cords by which the heddles are harnessed to the loom, is one which is often made by the weaver himself, but, as proper shedding depends upon this adjustment, it should be made by the trained tenter.

Relation of Machine to Operative.

Most industrial operations are dependent upon the interaction of two factors—the human and the mechanical—and the relative importance of these varies, of course, according to the nature of the operation. There are, on the one hand, operations in which the whole of the work is performed by the machine, which merely has to be minded (as is the case with automatic lathe operations, for example), and, on the other hand, operations in which the machine is virtually only a third hand to the worker, whose active co-operation and directive intelligence is constantly necessary (as is the case with certain operations in the boot and shoe trade, etc.). Between these two extremes lies the operation of linen weaving.

Both man and machine are capable of adaptation, but the former has a wider range and a greater facility of adaptation than the latter, which can usually only be altered within narrow limits after its construction is once completed; but it is obvious that the machine should be designed and constructed in such a manner that co-operation with it is neither difficult nor harmful to the worker.

If, however, for the sake of increased mechanical efficiency, the needs of the human element are disregarded in the design of a machine, the work of which depends partly upon its attendant, the increase of *mechanical* efficiency thus attained may be more than counterbalanced by the loss of actual *productive* efficiency which may result.

So far as the loom as a machine affects the efficiency of the weaver, it has already been said that improper adjustment, particularly of the shedding and picking mechanism, increases the

difficulty of weaving. Even the modern loom is by no means a perfect machine, and its mode of operation is necessarily such as to prevent its construction with the same degree of precision characteristic of many other machines But there is, no doubt, still room for improvement in the design of the picking mechanism, which, to ensure correct timing, should be such as to permit of ready and accurate adjustment.

In the shedding mechanism, the heddles which form the sheds are suspended from the heddle roller and straps by means of cords, and their lower extremities, beneath the warp, are also attached by cords to the tappet rods This method of harnessing the heddles to the loom is a very simple one which permits of ready, though sometimes rough, adjustment, but the cords are liable to expand or contract with changes in the atmospheric conditions of the shed. These changes are most marked during the first hour or so of the morning—and particularly of Monday mornings—and their effects, both directly, on the condition of the yarn, and indirectly, on the adjustment of the heddles, are undoubtedly responsible, in part, for the low efficiency of the weavers at these times. If the cords expand, the resulting "slack" has to be taken up by movement of the tappets before the heddles begin to move, with the result that the shed is not fully formed, and if they contract, the heddle is pulled taut, so that the heddle eyes are elongated and narrowed, thus increasing the risk of the yarn breaking during its passage through the eyes. In order to avoid the loss of efficiency traceable to this cause the harness cords might advantageously be replaced by some material or device* which is unaffected by atmospheric changes; wire has been actually tried for this purpose, but seems not to have proved sufficiently satisfactory to warrant its general adoption.

It is the general design of the loom, however—the disposition of the parts with which the weaver is principally concerned, and certain of its dimensions, which must be considered in estimating the facility with which the weaver is able to work with his loom. These parts and dimensions are shown in Fig A.

The height of the breast beam of the looms, which largely determines the attitude adopted by the weavers when drawing-in broken ends, ripping out, and tying, is 34 in., and this appears to be a convenient height for the average weaver. Weavers below the average height stand on a wooden platform between their looms, and are not, therefore, at a disadvantage in this respect, but very tall weavers have to stoop excessively when performing the operations mentioned, and do not appear anxious to reduce this necessity by altering the height of the breast beam, heddles, and back shell, which are adjustable within certain limits.

Tall weavers regard their height as an advantage, as it facilitates observation of the warp, but when attending to breakages

* Since this report was written a device with the object of overcoming this difficulty has been placed on the market

they have to adopt an accentuated stooping attitude. This may account for the condition of one or two very tall weavers observed to be noticeably round-shouldered and sunken-chested. It seems desirable that such weavers should have their looms to some extent adjusted to their height but, so long as they regard better observation of the warp as of primary importance, this is not likely to be done.

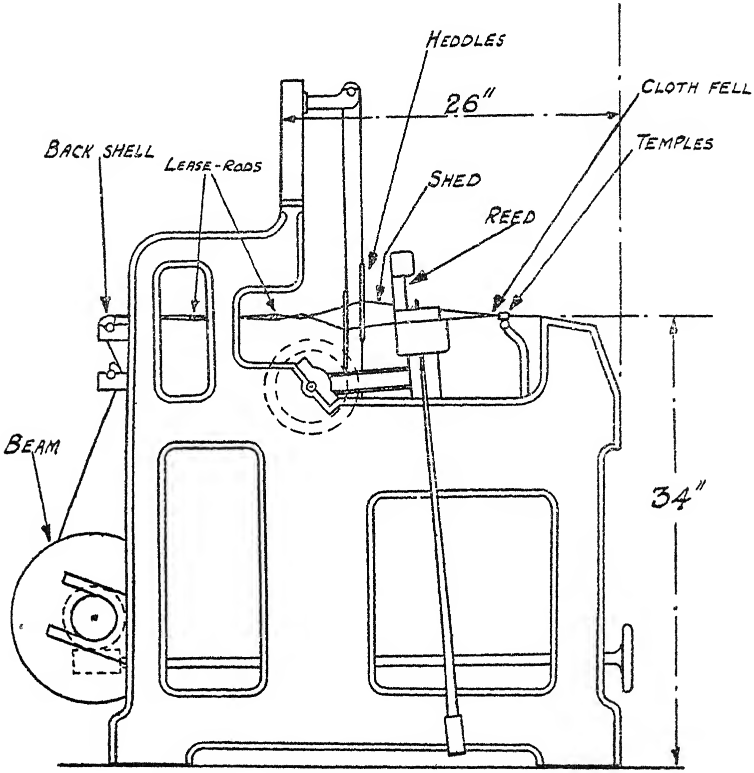

Fig. A. Cambric loom (side elevation).

The other principal dimension of the loom which affects the comfort of the weaver is its length from breast beam to back shell, which is about 3 ft. 8 in. Weavers who are at all able to do so usually attempt to tie a broken end from the front of the loom, even if the break occurs at the back shell, as this avoids walking round to the back of the loom. To do this, however, involves, in many cases, bending the trunk almost at right angles to the thighs and raising one leg off the floor, the lower part of the trunk only being slightly supported by the breast beam. More often, however, breaks occur somewhere between the lease-rods, and the weaver has then to reach to the back of the transverse frame supporting the heddle-roller shaft, a distance of 26 in. Even this necessitates an awkward stoop, but, as room must be allowed for the travel of the sley carrying the reed, for the heddles and

for the formation of the shed, it is probably impracticable to reduce the distance between the breast beam and the front lease-rod below its present limit.

The weaver, however, should be able to tie the majority of broken ends from the front of the loom without discomfort,* and in the future design of looms it may be found possible to rearrange the essential parts, behind the heddles, in such a way as to secure this end.

Atmospheric Conditions in relation to Linen Weaving and the Weaver.

It is necessary to consider the temperature of the air in which it is customary for certain work to be done in order to estimate, as far as possible, whether, having regard to the nature of the work, the temperature is such as to impair the efficiency of the workers or to increase their fatigue. The optimum temperature for bodily comfort will naturally vary according to the nature of the work done, *i.e.*, the more strenuous the work the lower should be the temperature in still air, since to secure bodily comfort the cooling power of the air must balance the rate of heat production of the body.

In the weaving of fine linen (as in certain other processes), a definite temperature or range of temperature is an essential condition from a technical point of view, and the problem of temperature is complicated by this fact, because there is necessarily a limit to the control which can be exercised over this factor without seriously increasing the difficulty and consequent cost of manufacture. In this case, then, not only the optimum temperature for the worker must be considered but also that which is best from the technical point of view, and if the two are not coincident a compromise must be made, which, while safe guarding the health of the former, will at the same time ensure reasonably economical production for the latter.

A high degree of humidity is also necessary for weaving certain kinds of linen cloth, and it is generally agreed that to obtain this the difference between the wet and dry bulbs should not exceed two degrees Fahrenheit irrespective of the temperature.

The higher the degree of humidity of the air, however, the lower will be its evaporative power, and beyond a certain limit, the free loss of heat by sweating will be impeded so that, if the

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* Elton has recently shown that breakages requiring repair from the back of the loom considerably affect the rate of production of weavers. One of the differences between good and bad weavers is the variation in their ability to deal with breakages occurring at the back of the loom in such a way as to avoid lengthy loom stoppages. Cf. "An Analysis of the Individual Differences in the Output of Silk-Weavers," by P. M. Elton, M Sc Reports of the Industrial Fatigue Research Board, No. 17. (Textile Series No. 4)

temperature and air movement are such that the body cannot be adequately cooled by radiation and convection alone, its temperature will rise.

Since a high humidity is required to keep the yarn in a damp condition, it may be difficult at very high shed temperatures to obtain adequate cooling power of the air by regulation of the rate of air movement without increasing the latter to an extent which would tend to dry the yarn and thus increase breakages.

The problem of ventilation in linen sheds is, therefore, difficult and complex, and, during the summer months, it is not always easy to avoid conditions which result in some discomfort to the weavers.

In the sheds in which this investigation was made the humidity was maintained at a practically constant value of 88 per cent. throughout the whole period of the inquiry, and, in order to determine the cooling power of the air and the rate of air movement in the sheds, some kata-thermometer* observations were made. These observations were made during the summer months, and the results show that in Shed A, at an average dry bulb temperature of 68·2° F. the dry kata cooling power† was 5·62, the evaporative power 9·84, and the velocity of the air 25 feet per minute. In Shed B, at an average temperature of 71·9° F., the results are 4·86, 9·29, and 24 feet respectively. The average temperature at which these results were obtained corresponds closely to the average temperature during the first statistical period of the investigation in each shed, and whilst the cooling power, of course, varied inversely with the temperature, so little variation in the rate of air movement was found that the latter may, for practical purposes, be regarded as constant. In view of this, and considering that a practically constant humidity was maintained, only the influence of variations of the wet bulb temperature on the efficiency of the weavers need be considered, and in this report, therefore, only wet bulb temperatures are given in presenting the data relating to variations of efficiency.

The low rate and small variation of air movement found is not surprising when the construction of weaving sheds and the control which has to be exercised of the condition of the air is considered. There are no windows which can be opened and the doors of the sheds are invariably kept closed, so that ventilation is practically dependent upon the means for introducing humidified

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* The kata-thermometer, designed by Dr. Leonard Hill, F.R.S., is an alcohol thermometer, of special construction and graduation, which measures the cooling power of the air by radiation, convection and evaporation; from its readings the air velocity can be calculated. For a description of this instrument and the method of using it, *see* "The Science of Ventilation and Open Air Treatment," Hill. Part I.

† Cooling power is expressed in milli-calories per square centimetre per second.

air. In Shed A this is done by a fan, driven from the line shafting, drawing fresh air from above the roof of the building, through a chamber to which exhaust steam from the condenser is admitted, from which it passes into the shed via a single large overhead duct In Shed B the method employed is similar, but the air is admitted into the shed by means of underground ducts provided with louvred gratings designed to direct the incoming air towards the weavers' beams. Three small exhaust fans are provided in one of the walls of Shed A, and a number of air outlets, communicating with a duct, are provided in the east wall of Shed B, but are only effective when the air-circulating system installed is in use, this being the case when the temperature reaches about 75°. During this inquiry the system was not in use.

Hill considers that the dry kata cooling power and the evaporative power for sedentary work should respectively be 6 and 12, and since weaving involves greater heat production than sedentary work, the values actually found for Sheds A and B must be regarded as too low in summer, although the winter values would be fairly adequate. During the summer months, therefore, when the shed temperature is often high, and production falls (as will be shown later) as a result of discomfort and fatigue of the weavers, it is desirable that the air velocity should be increased to some extent. If this were done it might be found that, in spite of any increased risk of drying the yarn, the fall in production at high temperatures might be minimized This is, however, a question which manufacturers themselves would do well to decide by experiment when suitable conditions prevail.

Description of Sheds.

Both of the sheds were constructed with the usual saw-tooth roof, the ratio of window to floor area in Shed A being approximately 1 : 3 and in Shed B approximately 1 : 2. The latter shed was therefore better lighted by daylight, and this advantage was increased by the fact that more light was reflected from the ceiling, which was considerably cleaner than that in Shed A. The sheds were heated by means of steam pipes suspended between 6 ft. and 7 ft. above the floor, and humidification was provided for by means already described. The looms were arranged with their long axes at right angles to the direction of the north light bays, so that equal illumination was provided at the front and back of them, and each loom was provided with a metal filament lamp for artificial lighting, this being suspended about 12 in. above the heddle-roller. These lamps were provided with shallow conical metal reflectors, which in Shed B were slightly tilted towards the back of the loom so that the filament was more effectively screened from the weavers.

The sheds were smaller than the average cotton weaving shed, but the capacity per weaver was about the same, and each shed contained about 300 looms, those to which pick-recorders were

fitted being situated approximately in the middle of the shed in both cases. All the looms were of the under-pick type and were driven from line shafting, and in Shed A about one-third of the looms were idle during the period of the investigation.

Owing to the trade conditions several changes in the hours worked in the sheds were necessary during the course of the investigation, which was thus divided into a number of statistical periods, the data for each of which have been dealt with separately.

Particulars of the number and distribution of hours of work in each of these periods are tabulated below.

Shed	Period	Duration (weeks)	Date	No of Hours per Week	No of Days per Week	Morning Spell	Afternoon Spell
A	1	5	26. 7 to 27. 8 20	45	5	8.00–12.30	1.30–6.00
	2	5	30. 8 to 30. 9.20	36	4	Do.	Do.
	3	5	11 10 to 12 11 20	40	5	Do.	1.30–5 00
	4	3	20.12 to 12 1.21	27	3	Do	1.30–6.00
B	1	11	3 8 to 14.10 20	36	4	8 00–12.30	1 30 6 00
	2	8	25.10 to 17.12 20	35	5	Do	1 30–4 00

Results Obtained.

Variations of Efficiency during the Day.

The average efficiency of the weavers at each hour of the typical day is given in Table I for each period of the investigation in both sheds, together with the wet bulb temperature at corresponding intervals. These efficiencies represent the percentages achieved of the maximum number of picks which could have been made in one hour by a non-stop loom. The latter was found by obtaining the speed of the looms, and the actual number of picks made was, of course, obtained from the pick-recorders. All the values given in the table are plotted graphically in Fig 1, which is based on the data contained in Table I (p. 26).

There is a marked similarity between the curves of efficiency and those of temperature in all periods and in both sheds, the rise of efficiency being coincident with that of temperature up to the middle of the afternoon spell, thus suggesting a close relation between these variables. The coincident fall in the general level of the efficiency and temperature curves which will be observed in the successive periods of the investigation is further evidence of the existence of such a relation, and it has been found from the correlation results on p. 22 that when a rise or fall of one degree of temperature occurs a corresponding rise or fall of roughly 1 per cent. of efficiency results. The hourly efficiency data for each period have, therefore, been approximately

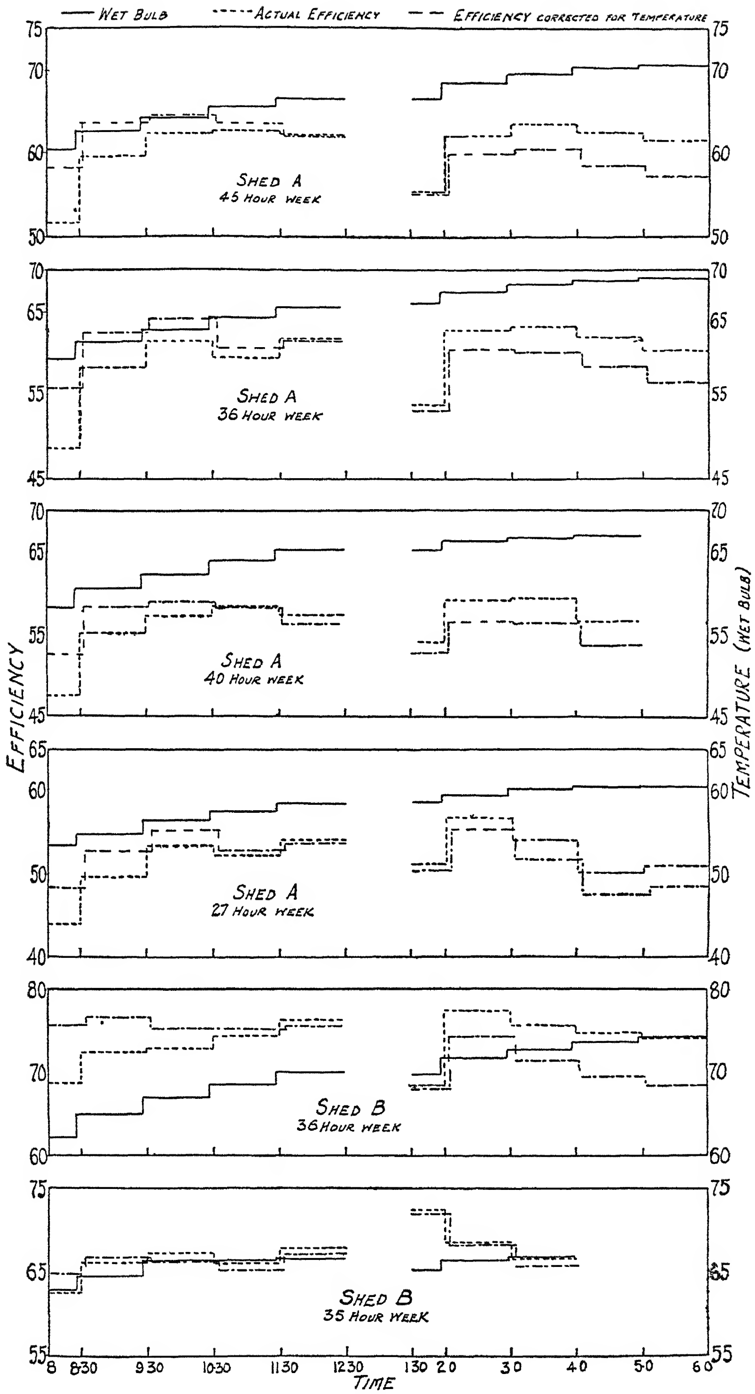

Fig. 1. Hourly variation of efficiency and temperature.

corrected for temperature variation, the mean daily temperature for each period being taken as the standard temperature. The efficiency figures corrected in this way are plotted in Fig. 1, together with the curves of actual efficiency.

The shape of the corrected curves conforms generally to that of most industrial work curves. There is the characteristic low efficiency at the beginning of the morning and afternoon spells, and a gradual fall of efficiency after the maximum point has been reached, this occurring about the middle of the morning spell, and, in the afternoon spell, usually during the second hour. In most of the curves for the morning spell a slight spurt is shown during the last hour, and an unusual feature of the afternoon curves is the incidence of the lowest point for the day at the beginning of this spell. On the whole, however, there is little difference between the efficiency at the beginning of either the morning or afternoon spells.

The corrected curves for the morning spell in Shed B show considerably less variation than do those for Shed A : this may be be due to a more consistent effort on the part of the workers in the former shed.

Efficiency during the afternoon spell will be seen to be lower than during the morning spell, and there is a tendency for the fall of the curve towards the end of the day to increase in the successive periods of the investigation, and this will be shown to be due largely to the reduction of illumination during the latter months of the year and to the use of artificial light.

Change of hours of work appears to have had little effect upon the variations of efficiency.

The level of efficiency in Shed B is higher than in Shed A, although the average kind of cloth woven in both sheds was practically identical. This difference of efficiency is partly an effect of the higher temperature in Shed B, but if the curves for the respective sheds are compared during the two 36-hour-week periods it will be seen that efficiency begins to fall earlier in the day in Shed B than in Shed A, thus suggesting that the high efficiency in the former shed is partly due to greater effort of the weavers, with a consequent earlier onset of fatigue.*

Relation of Temperature to Efficiency.—The influence of temperature on the diurnal variation of efficiency is shown in Fig. 2

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* There is some doubt whether the two groups of weavers whose efficiency was studied were equally representative of the average weaver's skill in their respective sheds, although in each shed the weavers composing the experimental group were chosen at random. For this reason, however, and because the kind of cloth woven by the respective groups was not exactly similar, it must be understood that comparisons drawn in this report between efficiencies in the two sheds are not necessarily true of the sheds as a whole but only of the particular groups of weavers concerned.

(*see also* Table II, p. 27), from which it is apparent that the afternoon increase of temperature almost invariably results in a

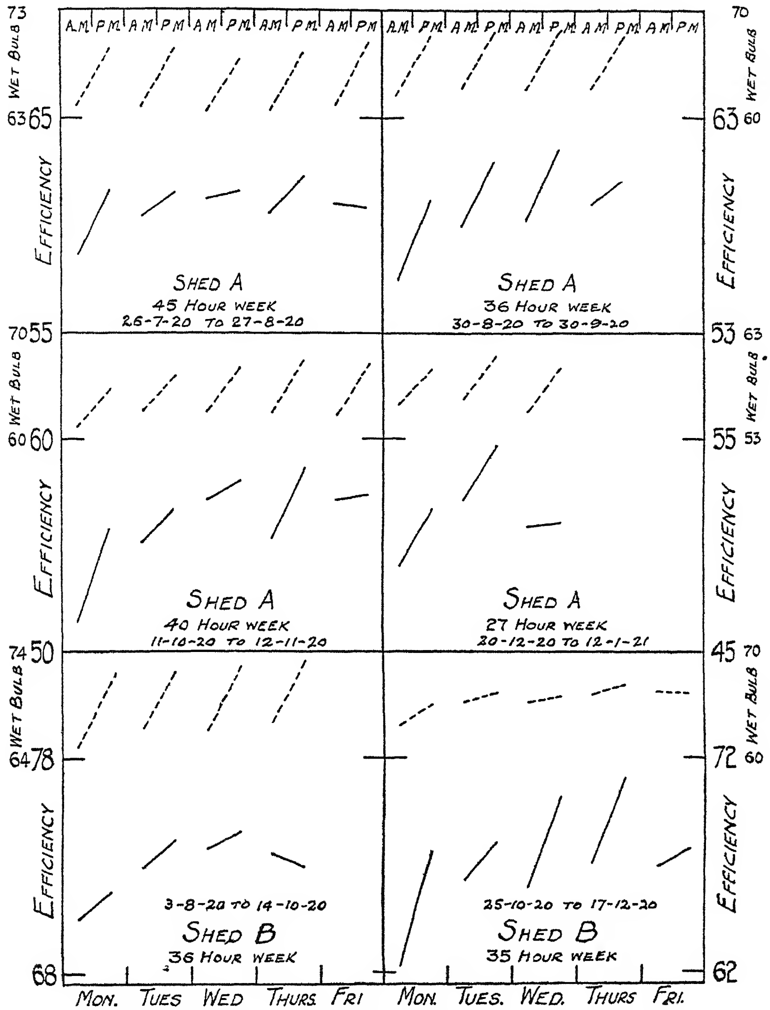

Fig 2. Diurnal variation of efficiency and temperature

corresponding increase of productive efficiency. This effect is generally most marked on Monday, and is only reversed on the last day of the week during the first statistical period of investigation in each shed. There is, however, a general tendency for the effect of temperature to become less towards the end of the week, owing to the increasing counter-effect of fatigue and other disturbing factors Among these factors may be mentioned the extra attention which weavers often give to one of their looms, at the expense of the other, in order to get a "cut" off before "making up" time, and the relaxation of effort which they permit themselves after such a cut is finished. It is, however,

doubtful whether during this inquiry the afternoon efficiency on the last working day of the week was very appreciably reduced by this factor, as the data obtained shows that the number of cuts completed at this time was not much greater than the number completed on other afternoons.

In only one week during the whole period of investigation was the characteristic diurnal rhythm of productive efficiency reversed on every day of the week. This occurred in Shed B, during the ninth week of the 36-hour-week period, during which the highest temperature of the period was reached, and the data for this week suggest a most important conclusion in regard to the relation between temperature and efficiency.

The morning and afternoon efficiency and wet bulb temperature for the three whole days of this week (Monday morning was not

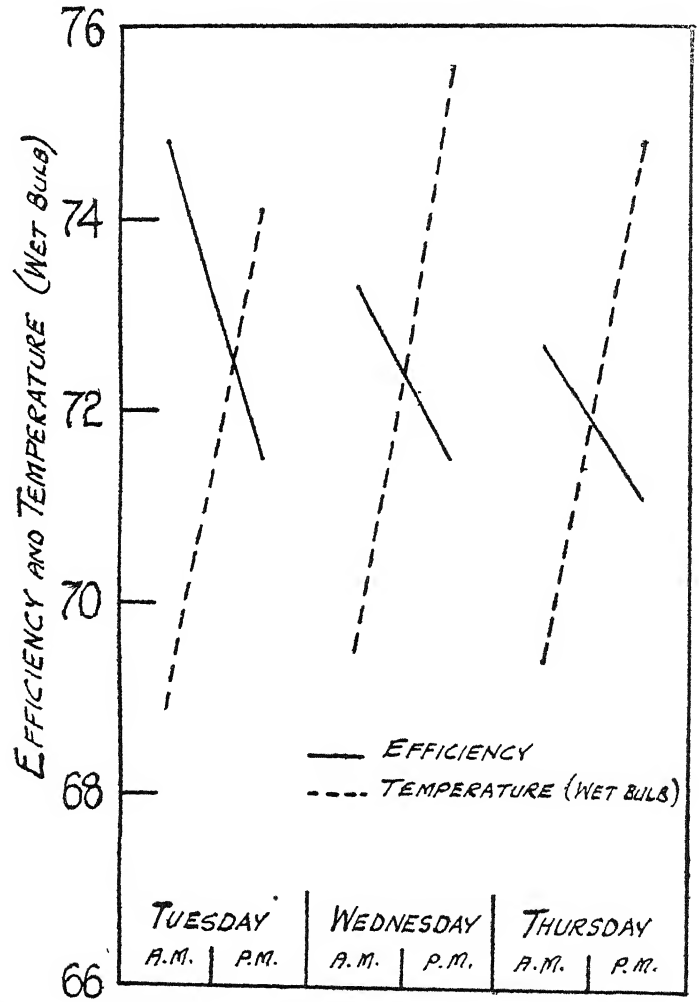

Fig 3. Diurnal variation of efficiency and temperature during a hot week.

worked) are plotted in Fig. 3 Investigation failed to reveal any unusual factor, apart from temperature, operating during this particular week which could account for the consistent reversal of the normal efficiency order of the spells. It must be concluded, therefore, that the effect observed is due to the fact that the afternoon wet bulb temperature, which exceeded 74° F., reached a level at which its inimical influence upon the comfort and fatiguability of the weavers was such as to prevent attainment of the usual high afternoon efficiency.

In Fig. 4 the morning and afternoon efficiency and wet bulb temperature are plotted for five isolated days during the first period of investigation in Shed B, when the afternoon wet bulb temperature exceeded 73° F.

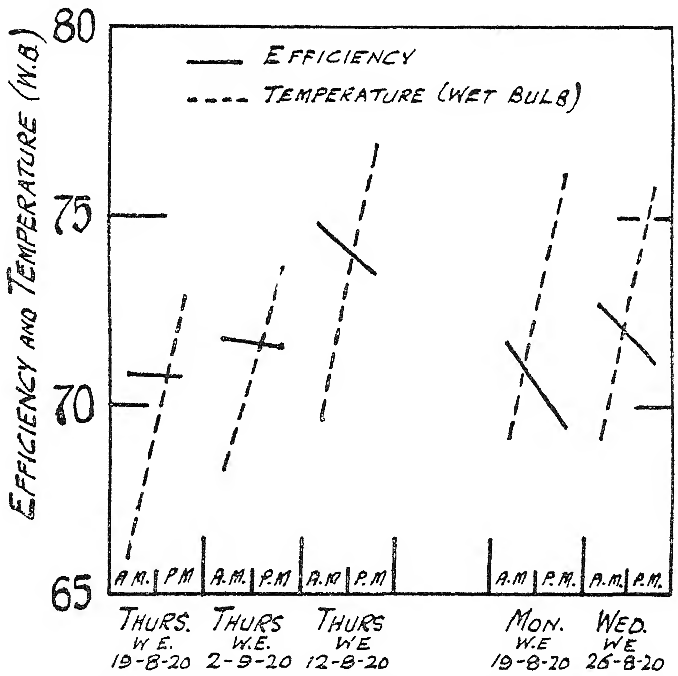

Fig 4 Variation of efficiency and temperature during five isolated hot days.

On each day the normal diurnal rhythm of efficiency was reversed. Such reversal occurred as a rule on Thursday during this period, but it is significant that the extent of the afternoon fall in efficiency on the three Thursdays in question increases as the excess of temperature over 73° F. increases.* The Monday and Wednesday results shown are even more striking, since with a lower wet bulb temperature the afternoon efficiency on these

* All three Thursdays happen to be pay-days, but even if the effect of making up time contributed to the afternoon fall in efficiency it is very improbable that it happened to cause this fall to increase as the temperature increased.

days, and particularly on Mondays, was invariably higher than that of the morning.

It is evident that a limit of temperature can be reached beyond which its effects upon the work and upon the workers are opposed. Haldane found that when work comparable to that involved in weaving was done, and light summer clothing worn, discomfort was experienced when the wet bulb reached 73° to 74° F., and an investigation of the body temperature of linen weavers by Legge has shown that at similar wet bulb temperatures the body temperature begins to rise above the normal * The results of the present investigation of output confirm the results of these earlier inquiries and seem to justify the conclusion that, if undue fatigue and consequent reduction of efficiency is to be avoided, the wet bulb should not be allowed to exceed or continue long at 75° F At such a temperature (with the dry bulb two degrees higher and the air velocity as in Shed B) the dry and wet kata cooling powers would be 3·3 and 8·3 respectively.

Relation of Lighting to Efficiency.—The influence of illumination upon efficiency is shown in the curves of hourly variation in Shed A during the 40 and 27-hour-week periods. During the last two weeks of the former period work was stopped as soon as the daylight became inadequate, so as to avoid the use of artificial light, but the effect of carrying on the work, even for a short time, with a poor illumination is seen in the magnitude of the fall of the curve during the last hour of the day. This is twice as great as the corresponding fall in the two preceding periods of the investigation when there was adequate daylight. This effect is more clearly seen in Fig 5, in which the hourly variations are plotted separately for the first three and the last two weeks of this period, the efficiency for the best hour of the day being here regarded as 100 per cent.

During the first part of the period the fall of the curve in the last hour is no greater than that which occurs in the 45 and 36-hour-week periods, but during the second part of the period the corresponding fall is nearly five times as great, the actual difference between the two falls, attributable to the effect of inadequate illumination, being 6·5 per cent.

A similar and greater effect is observed in the results for a subsequent week when the failing light necessitated earlier stoppage. This is also shown in Fig. 5, from which it will be seen that the excess of efficiency lost during the last hour amounts roughly to 11·5 per cent. From data available in regard to the average daylight illumination during the month of November, to which the results discussed relate, it is estimated that the general

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* Report of the Departmental Committee on Humidity and Ventilation in Flax Mills and Linen Sheds. Cd. 7433. pp. 39 and 41 et seq.

illumination of the shed at the time work was stopped was of the order of 2 foot-candles.*

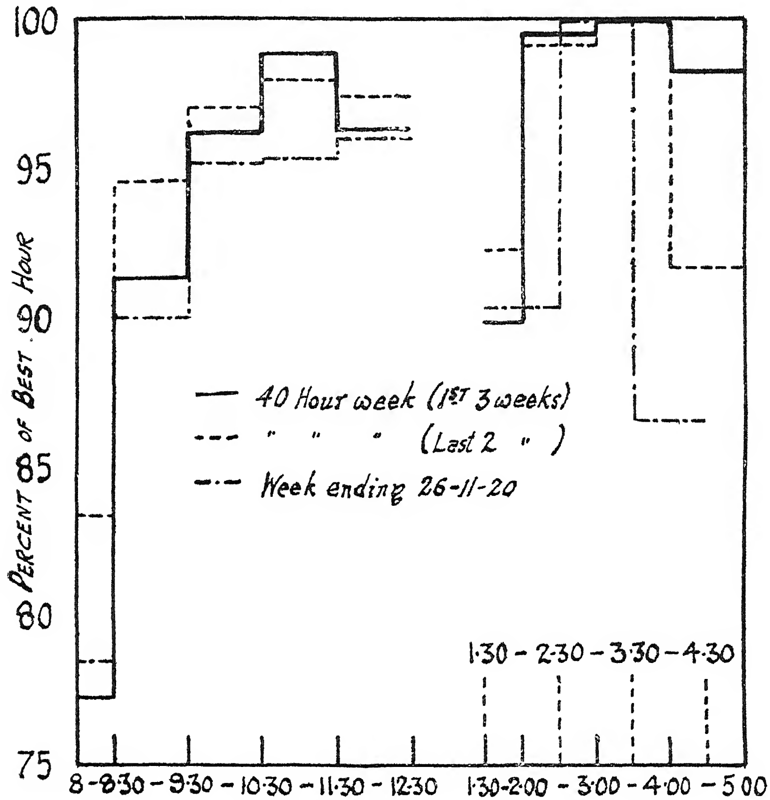

Fig. 5. Relative hourly efficiency (typical day) for the beginning and end of the 40-hour-week period and for the week ended 26th Nov., 1920. (Shed A.)

During the 27-hour-week period artificial light was used during practically the whole of the first hour of the day, but little, if any, effect of its use at that time can be traced. In the afternoon, however, when artificial light was used during the last two hours, efficiency falls from 10 to 11·5 per cent. (*see* Fig. 1) as compared with the fall of 2 to 3·5 per cent. which occurred under daylight conditions during the first two periods of investigation.

The relative efficiency throughout the day during an isolated week in December is shown in Fig. 6, when artificial light was used during the last three-quarters of an hour. The fall of efficiency is here 21·5 per cent., and there is also a marked fall during the preceding hour when daylight illumination was rapidly diminishing. The slight increase of efficiency observed in the last hour of the day during the 27-hour-week (*see* Fig. 1)

* The foot-candle is the unit of illumination, and is the illumination from a light source of 1 candle-power received normally on a surface distant 1 ft. from the source.

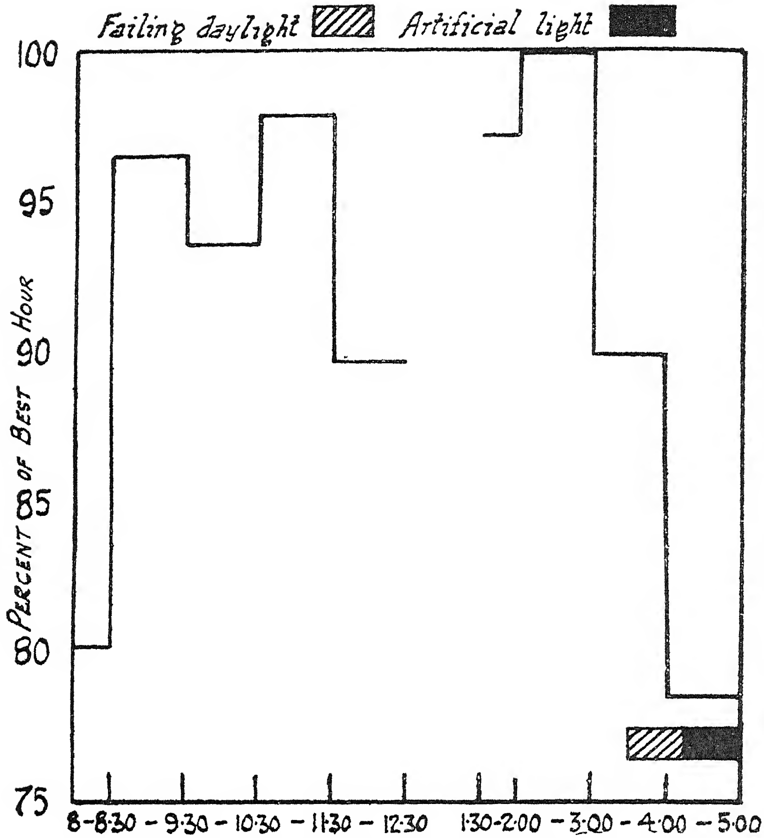

Fig. 6. Relative hourly efficiency (typical day) for week ended 3rd Dec., 1920. (Shed A.)

suggests that the effect of artificial light upon efficiency may be most marked during the first hour of its use, and that some improvement is to be expected when the weavers become accustomed to the change of lighting.

These results show that the average loss of efficiency attributable to the effects of artificial lighting is of the order of 11 per cent., and this is in close agreement with the conclusion reached by Elton in a similar investigation of output in silk weaving.*

The actual illumination of the work by artificial light was good, the maximum varying between 5 and 8 foot-candles. This would appear to be an adequate illumination, having regard to the fineness of the work and the colour of the material used. Diversity† of illumination is, however, an important factor in artificial lighting.

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* "A Study of Output in Silk-weaving during the Winter Months," by P. M. Elton, M.Sc. Report No. 9 of the Industrial Fatigue Research Board. (Textile Series No. 3.) p. 55

† Diversity is expressed as the ratio of maximum to minimum illumination.

Obviously, if there is considerable diversity of illumination over the area of work, some parts of the latter may be adequately, and other parts very inadequately, lighted Such conditions are unlikely to arise with natural lighting, at all events in a weaving shed, but are often found with artificial lighting, particularly when local lights are relied upon for the illumination of fairly large working areas, as in most weaving sheds. Thus, although the illumination at the centre of the cloth fell was adequate in the present case, the illumination at the selvedges and at the back shell was only about 1·5 to 2·0 foot-candles. The whole of the area defined by the selvedges and the breast beam and back shell of the loom is important to the weaver, since the yarn may break at any point, and frequently does so at the selvedges, and adequate and uniform illumination is, therefore, necessary if breakages are not to be overlooked and efficiency thereby reduced. As the weaver has to scan the whole area occupied by the warp, the continual changes of adaptation necessitated if there is considerable diversity of illumination necessarily fatigue the eye, breakages are not observed as soon as they occur, and output is reduced owing to the time which has to be wasted in picking out shots put in after an unobserved broken end has been woven in.

Local illumination may also affect efficiency indirectly, as it is possible that the general darkness of the shed, due to the absence of any general lighting, may have a somewhat depressing effect upon the weavers.* There is also no doubt that glare is responsible to some extent for the efficiency lost under artificial light in the present case. All the light sources were suspended practically at eye-level, and were very imperfectly shaded by shallow conical metal shades. The light from the lamps therefore fell directly into the eyes of the weavers when looking at the warp, especially behind the heddles, and the glare thus occasioned must have increased the difficulty of perceiving broken ends. This glare was also accentuated by the excessive contrast between the bright illuminant in the central line of vision and the dark surroundings and consequent low illumination of the peripheral field of vision.

It might perhaps be found that considerably less efficiency would be lost under artificial light if good general lighting was substituted for local lighting, or if local lighting was supplemented by a certain amount of general illumination. This would give the shed a more cheerful aspect, approximating more nearly to daylight conditions, and if properly arranged, would reduce the diversity of illumination on the work. Glare should also be eliminated, either by mounting the lamps higher and using units of higher intensity so as to maintain the present maximum illumination, or by effectively shading them so that the filament is normally invisible to the weavers.

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* Experiments recently carried out by the Departmental Committee on Lighting in Factories and Workshops tend to confirm the view that excessive contrast between illumination at the point of work and the surroundings is undesirable.

Daily Variations of Efficiency.

In view of the relation between temperature and efficiency suggested by the study of their hourly variations, the mean daily efficiency has been correlated with the mean daily wet bulb temperature during the first three statistical periods of investigation in Shed A and during the two periods of investigation in Shed B, and the results are given in Table A.

TABLE A.—*Correlation of Efficiency with Wet Bulb Temperature in Sheds A and B.*

	Shed A.		Shed B.	
	Effcy., %	W.B Temp	Effcy., %	W.B. Temp.
Mean	58·5	65·3	70·3	67·7
Mean Variation	±2·37	±1·97	±3 22	±2·36
Standard Deviation	2·98	2·38	3·86	2·83
Number in Series	70		82	
Sum of Products of corresponding Individual Deviations	294·53		635 69	
Co-efficient of Correlation ..	+0·59		+0·71	
Probable Error of Co-efficient ..	±0·058		±0 037	

The co-efficients found justify the conclusion that, under the conditions obtaining during this investigation, there is a definite and direct relation between temperature and efficiency in linen weaving,* and show that variations of efficiency day by day are, in the main, due to corresponding variations of temperature. The method of correlation used will only give a perfect result of ±1·0

* Experimental proof of this relation was obtained by the Departmental Committee on Humidity and Ventilation in Flax Mills and Linen Factories. Experiments were made by the Committee in Shed B, in which the number of warp breakages and the time occupied in weaving unit length of cloth were found when the wet bulb temperature varied and the difference between the wet and dry bulbs remained practically constant. The results summarized in the following table (extracted from Appendix XII of the Committee's Report, Cd 7433) show that warp breakages and time occupied decrease as the temperature rises.—

Wet Bulb Temp.	Difference between W.B. & D.B Temp.	Warp Breakages.	Time Occupied.
61·6	1·5	11·3	52·0
64·0	1·7	11·1	54·0
65·7	1·5	7·3	47·6
68·5	1·6	7·6	46·0
72·0	1·7	6·3	42·0

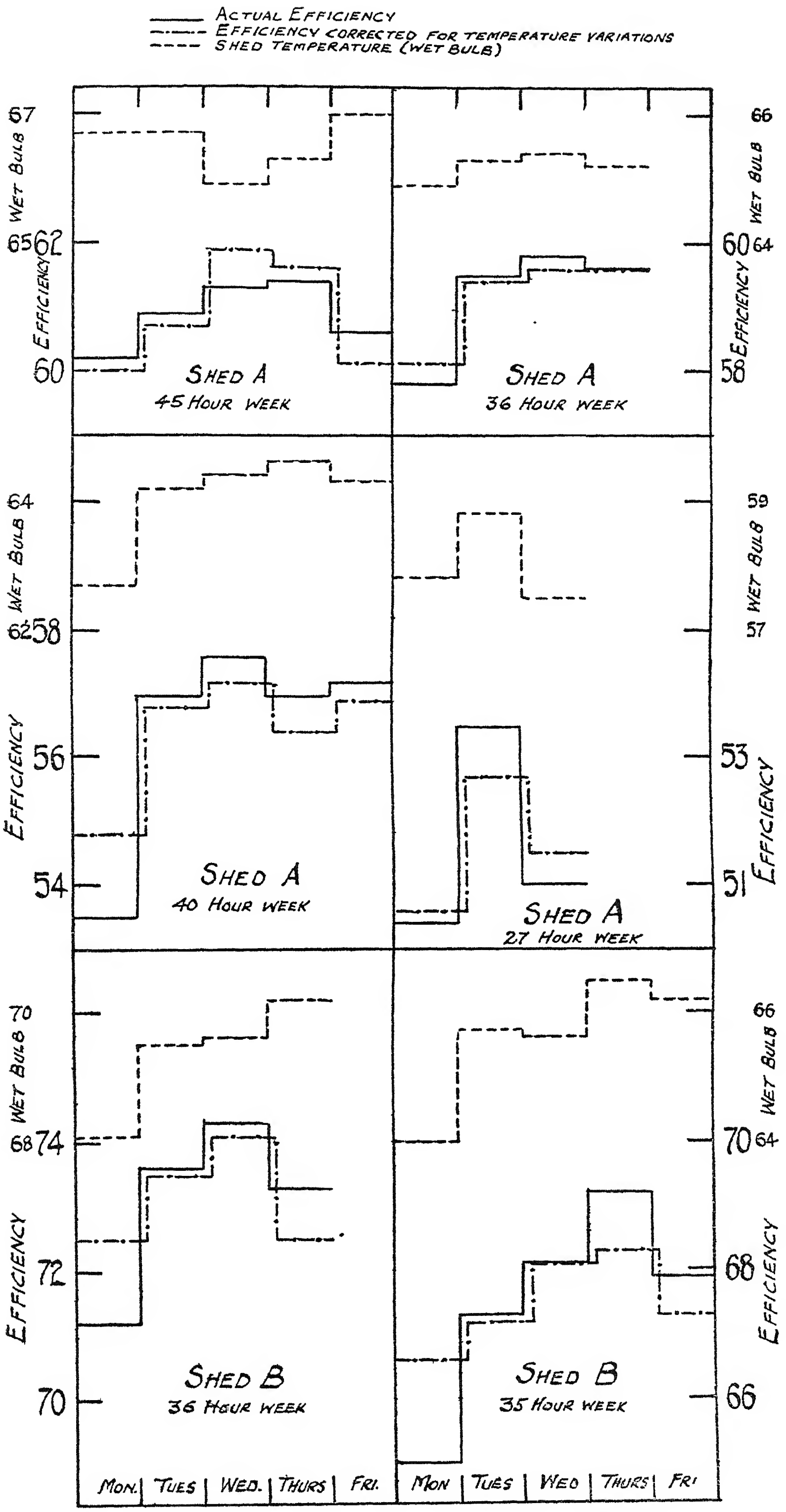

Fig 7. Daily variation of efficiency and temperature.

when the relation between the correlated variables is defined by a linear law, and whilst there is no reason to suppose that such a law holds good for the relation between temperature and efficiency, the magnitude of the co-efficients obtained suggests that the portion of the efficiency-temperature curve within the limits of variation experienced approximates fairly closely to a straight line.*

The daily variation of efficiency and temperature in both sheds during the typical week is shown in Fig. 7 (and are given in full in Table III, p. 27) for all periods of the investigation. It is obvious that the shape of the efficiency curves follows that of the temperature curves, and the general shape of the former is very similar to that of the curves of hourly variation of efficiency (*see* Fig. 1). The corrected curves show that efficiency is lowest on Monday, and this is usually attributed to loss of practice and "settlement" as a result of the week-end break. The effect is accentuated in the curves of actual efficiency owing to the influence of temperature, which is almost invariably at its lowest on Monday. Maximum efficiency is attained on Wednesday, probably because by then the factors operating against high efficiency at the beginning of the week have lost their influence, whilst those inimical to high efficiency towards the end of the week have not yet begun to affect the weavers It will be seen that the characteristic fall of efficiency on the last day of the week occurs even when the duration of the working week is almost halved, and it can, therefore, hardly be regarded as the result, to any great extent, of fatigue. It appears rather to be evidence of the operation of disturbing factors, largely psychological, which are probably inseparable from the end of a working period, whether it be a spell of a few hours, a day, or a week. Further, when the week is shortened, maximum efficiency is generally attained earlier and thus tends to retain its position relative to the beginning and end of the week, and a similar effect was noticed in the case of the hourly variations of efficiency, when the length of the afternoon spell was shortened.

Weekly Variation of Efficiency.

In Fig. 8,† in which the weekly variation of efficiency and temperature is shown, the dependence of the former upon the latter is clearly seen in the shape of the respective curves, whilst the effect upon efficiency of seasonal changes of temperature is evident from the general downward trend of both the curves. The variation of efficiency from week to week, which is seen in the curves corrected for temperature variation, is partly the result of changes in the kind of cloth woven, which affected the average difficulty of the work.

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* This approximation to linearity has been confirmed by plotting the efficiency—temperature curve.

† *See* also Table IV (p. 28).

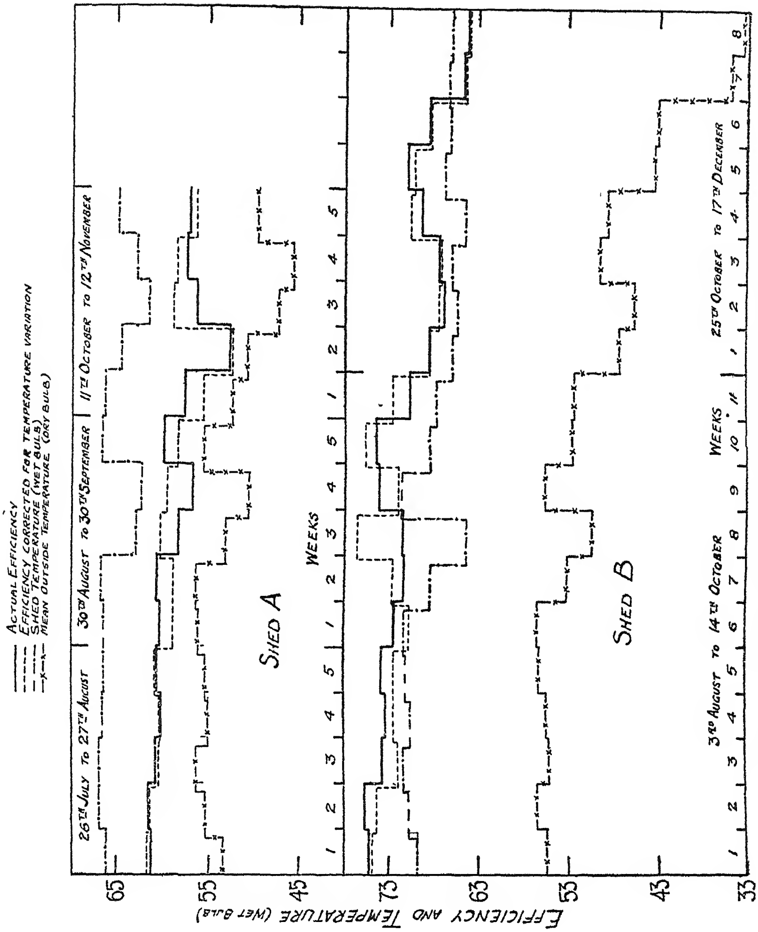

Fig 8 Weekly variation of efficiency and temperature.

Conclusions.

(1) In any work period (spell, day, or week), the duration of which is known to the worker, a number of factors normally combine in determining the variations of efficiency according to a definite sequence. In linen weaving, when the relative humidity is practically constant, this sequence is modified mainly by the effect upon the work of variations of temperature.

(2) There is evidence to show that the economic limit of temperature for fine linen weaving is reached when the wet bulb temperature exceeds 73° F. Up to this limit, increase of temperature results in increase of productive efficiency, but beyond it efficiency falls owing to discomfort and fatigue of the weavers.

(3) Subject to conclusion (2), the normal conditions of temperature in linen sheds ensure that the afternoon spell will be productively superior to the morning spell.

(4) Variation of illumination affects efficiency, and the use of artificial light, under the conditions observed, reduces efficiency approximately by 11 per cent. of its normal daylight value. So far as this effect is avoidable, it depends probably on glare, shadow effects, and absence of general lighting rather than on amount of illumination.

(5) The results obtained do not enable definite conclusions to be drawn as to the relative merits of the different arrangements of hours of work tried during the investigation.

TABLES.

TABLE I.—*Hourly Variation of Efficiency and Temperature.*

Shed.	Period		8–8.30	8.30–9.30	9.30–10.30	10.30–11.30	11.30–12.30	1.30–2.0	2.0–3.0	3.0–4.0	4.0–5.0	5.0–6.0
Shed A.	45 Hour Week	Efficiency.	51·8	59·6	62·2	62·6	62·1	55·5	62·0	63·5	62·4	61·5
		Mean Var.*	1·1	0·9	1·1	0·8	1·1	0·8	1·7	1·1	1·2	1·2
		Corr. Effcy.	58·2	63·6	64·5	63·5	62·0	55·1	59·9	60·4	58·4	57·2
		W.B. Temp.	60·3	62·6	64·2	65·6	66·6	66·7	68·5	69·6	70·3	70·6
	36 Hour Week	Efficiency.	48·8	58·3	61·4	59·6	61·9	53·8	62·8	63·2	62·0	60·5
		Mean Var.	3·0	2·3	1·7	1·5	1·4	0·8	1·3	1·3	0·6	1·1
		Corr. Effcy.	55·8	62·4	64·0	60·7	61·7	53·0	60·5	60·1	58·4	56·6
		W.B. Temp.	59·2	61·2	62·7	64·1	65·4	66·0	67·5	68·3	68·8	69·0
	40 Hour Week	Efficiency.	47·5	55·2	57·5	58·6	57·6	54·1	59·2	59·5	56·9	—
		Mean Var.	3·0	2·2	1·0	1·4	1·6	1·7	1·1	2·2	2·0	—
		Corr. Effcy.	52·7	58·5	59·1	58·6	56·4	52·9	56·8	56·7	53·9	—
		W.B. Temp.	58·5	60·8	62·4	64·0	65·3	65·2	66·4	66·8	67·0	—
	27 Hour Week	Efficiency.	44·0	49·8	53·4	52·2	54·1	51·1	56·7	54·0	50·1	51·0
		Mean Var..	0·8	1·4	0·4	2·1	1·5	2·3	1·9	0·5	1·6	1·6
		Corr. Effcy.	48·5	52·9	55·1	52·8	53·7	50·4	55·2	51·8	47·6	48·4
		W.B. Temp.	53·5	54·9	56·3	57·4	58·4	58·7	59·5	60·2	60·5	60·6
Shed B.	36 Hour Week	Efficiency.	68·8	72·3	72·8	74·4	76·3	68·5	76·5	74·8	73·8	73·1
		Mean Var.	2·4	2·3	1·9	1·5	2·2	3·2	1·5	2·6	1·9	1·9
		Corr. Effcy	75·9	76·8	75·3	75·3	75·7	68·0	74·2	71·2	69·4	68·3
		W.B. Temp.	62·2	65·0	67·0	68·6	70·0	69·8	71·7	72·8	73·7	74·1
	35 Hour Week	Efficiency.	62·4	66·1	67·2	66·0	67·9	72·5	68·6	66·4	—	—
		Mean Var..	3·3	1·6	2·7	1·3	1·2	4·9	2·0	1·6	—	—
		Corr. Effcy.	64·9	66·8	66·3	65·2	67·1	72·0	68·2	65·6	—	—
		W.B. Temp.	62·7	64·6	66·2	66·2	66·3	65·2	66·4	66·8	—	—

* The mean variation is the mean of the differences, neglecting signs, between the average efficiency at any hour and the individual values in the series from which the average is obtained. It is a measure of variability.

TABLE II.—*Diurnal Variation of Efficiency and Temperature.*

Shed.	Period		Monday. a m.	Monday. p m	Tuesday. a m	Tuesday. p.m	Wednesday. a m	Wednesday. p.m	Thursday a m.	Thursday p m	Friday. a m	Friday. p m
Shed A.	45 Hour Week	Efficiency . Mean Var. W B Temp	58 7 1 8 64 1	61 6 1 3 69 2	60 4 1 9 64 0	61 4 2 0 69 4	61 2 1 0 63 5	61 5 1 1 68 3	60 6 1 8 63 6	62 3 1 5 69 0	61 0 1 2 64 1	60 8 0 9 69 9
	36 Hour Week	Efficiency . Mean Var . W B. Temp	55 5 2 1 62 1	59 2 1 0 67 7	57 9 1 5 62 7	61 0 1 6 68 0	58 1 1 6 62 6	61 5 1·4 68 2	58 9 3 2 62·7	60 2 1·4 67 7	— — —	— — —
	40 Hour Week	Efficiency . Mean Var.. W.B. Temp	51 4 2 5 61 1	55 8 2 1 64 7	55 3 1·7 62 7	56 8 2 6 66 0	57 2 2 6 62 6	58 0 2 2 66 7	55 5 1 8 62 4	58 7 1 9 67 3	57 2 1 5 62 2	57 4 3 0 67 0
	27 Hour Week	Efficiency . Mean Var . W B Temp	49 0 1 2 56 1	51 8 1 2 59 4	52 2 0 8 56 7	54·7 1 5 60 7	50 9 1 1 55 4	51 1 1 7 59 5	— — —	— — —	— — —	— — —
Shed B.	36 Hour Week	Efficiency . Mean Var W B. Temp	70·6 1 8 65 0	71 8 1·4 71 2	73·0 1·4 66 8	74 2 1·2 72 1	73 9 1 2 66 5	74 7 1·6 72 6	73 6 1 3 67 2	73 0 1 7 73 1	— — —	— — —
	35 Hour Week	Efficiency . Mean Var.. W B Temp	62 3 1 6 63 0	67 7 2 6 64 9	66 4 2·4 65 3	68·1 3 3 66 1	66 0 1 9 65 3	70 1 3 0 65 9	67 2 1·6 66 0	71 1 2·9 66 9	66 9 1 4 66 2	67 8 3 6 66 1

TABLE III.—*Daily Variation of Efficiency and Temperature.*

Shed.	Period.		Mon.	Tues	Wed	Thurs	Fri.
Shed A.	45 Hour Week	Efficiency .. Mean Var. .. .. Corr. Effcy. .. .. W B. Temp.	60 2 1·6 60·0 66·7	60·9 2·0 60·7 66·7	61·3 1·0 61·9 65·9	61 4 1·6 61·6 66·3	60·6 1·0 60·1 67·0
	36 Hour Week	Efficiency .. .. Mean Var. .. .. Corr Effcy. . .. W.B. Temp . ..	57·8 1·5 58·1 64·9	59·5 1·6 59·4 65·3	59·8 1·5 59·6 65·4	59·6 2·3 59·6 65·2	— — — —
	40 Hour Week	Efficiency . . Mean Var. .. Corr. Effcy .. W B Temp. .	53·5 2 3 54 8 62 7	57·0 2·1 56·8 64·2	57·6 2 4 57 2 64 4	57·0 .1·9 56·4 64 6	57·2 2 3 56·9 64·3
	27 Hour Week	Efficiency .. Mean Var. .. . Corr Effcy. .. . W B. Temp.	50·4 1·2 50·6 57·8	53·5 1·0 52·7 58·8	51·0 1·2 51·5 57·5	— — — —	— — — —
Shed B	36 Hour Week	Efficiency .. .. Mean Var. .. .. Corr. Effcy .. .. W.B. Temp	71·2 1·5 72·5 68·1	73·6 1·1 73·5 69·5	74·3 1·2 74·1 69·6	73·3 1·5 72·5 70·2	— — — —
	35 Hour Week	Efficiency .. .. Mean Var. .. .. Corr. Effcy. .. .. W.B. Temp.	65·0 1·9 66·6 64·0	67 3 2·3 67·2 65·7	68 1 2·0 68·1 65·6	69·2 1·9 68·3 66·5	67·9 1·9 67·3 66·2

TABLE IV.—*Weekly Variation of Efficiency and Temperature.*

Shed A.

Period	Effcy	M.V.	Corrd. Effcy	W.B Temp.	Mean Outside Temp
45 Hour Week	61·3	1·2	61·7	66·1	53·3
	61·6	1·6	61·4	66·9	55·3
	60·8	1·3	60·4	66·9	56·4
	60·1	1·1	60·2	66·4	55·0
	60·6	1·3	60·8	66·3	55·2
36 Hour Week	60·3	1·2	58·9	66·3	56·1
	60·6	1·6	58·9	66·6	56·4
	58·2	1·4	60·2	62·9	53·1
	56·9	1·2	59·6	62·2	50·5
	60·0	0·9	58·3	66·6	55·7
40 Hour Week	57·9	2·0	55·7	66·2	52·4
	52·8	1·5	52·3	64·5	50·8
	56·6	1·8	59·0	61·6	47·4
	57·6	1·9	58·7	62·9	45·8
	57·3	1·3	56·4	64·9	49·7

Shed B.

Effcy	M.V	Corrd Effcy.	W.B Temp.	Mean Outside Temp	Period
75·2	0·8	74·9	69·8	55·3	36 Hour Week
75·6	1·0	74·3	70·8	56·4	
73·6	0·9	71·9	71·2	55·0	
73·2	1·5	72·3	70·4	55·2	
73·8	1·2	72·3	71·0	56·1	
72·3	1·3	70·7	71·1	56·4	
71·3	0·7	72·6	68·2	53·1	
71·4	0·9	76·6	64·3	50·5	
74·1	1·0	72·0	71·6	55·7	
74·5	0·7	75·7	68·3	52·6	
70·8	1·7	72·6	67·7	52·4	
68·5	1·6	68·5	65·9	47·4	35 Hour Week
66·9	1·8	67·4	65·4	45·8	
67·3	1·8	67·2	66·0	49·7	
69·3	3·1	70·7	64·5	48·8	
71·0	1·1	70·2	66·7	43·6	
68·4	2·2	68·2	66·1	43·1	
64·9	1·3	64·6	66·2	34·9	
64·3	1·5	64·2	66·0	33·3	

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PREFACE.

The present report, dealing with the atmospheric conditions in weaving sheds, has an important bearing on a question which has long been the subject of controversy in the cotton industry.

For the weaving of certain classes of cotton cloth, moisture (in the form either of steam or of water) is introduced into the air of the sheds, in order to maintain the degree of humidity desirable for successful weaving. This practice, which has always been strongly objected to on the part of the operatives, has for many years been controlled by statutory regulations, the requirements of which have been changed from time to time. The question has always been recognised as a complex one, chiefly because the physiological effects of humidity, temperature, and ventilation on the comfort and health of the operatives, must be considered in conjunction with their physical effects on the yarn in manufacturing. It may be of interest, therefore, to trace briefly the successive stages in legislation from the beginning up to the present time.

The first protest against the artificial humidification of weaving sheds appears to have been made in 1882 by the Parliamentary Committee of the Trade Union Congress, in consequence of which an official inquiry was held by Dr. J. H. Bridges and Mr. E. H. Osborn [1], who arrived at the conclusion that the principal default in weaving sheds at that time was lack of efficient ventilation and made recommendations for ensuring a sufficient standard.

In 1889, following some local inquiries in Lancashire, an Act* was passed, in which for the first time the maximum limits of the humidity permissible in the atmosphere for different temperatures were tabulated, and effect was given to the recommendations as to ventilation contained in the Report of 1882 by prescribing for the admission of at least 600 cub. ft. of fresh air per hour for every person employed.

These restrictions, however, failed to satisfy the operatives, and in 1896 the Weavers' Associations again approached the Home Office with a demand for the total abolition of "steaming." A Departmental Committee, under the Chairmanship of Sir Henry Roscoe, was thereupon appointed by the Secretary of State to inquire into the working of the Act of 1889. Their Report [2] made in 1897 contained certain recommendations, most of which were embodied in a Statutory Order of the Secretary of State

* Cotton Cloth Factories Act, 1889. (52 & 53 Vict. chap. 62).

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under powers conferred on him by a special Act.† In this Order the permissible limits of humidity were retained unchanged, but important provisions were introduced relating to temperature and ventilation. Thus, in order to reduce the rise of temperature within the sheds, the white-washing of the roofs of the sheds in summer and the lagging of the steam-pipes were made compulsory, whilst as regards ventilation a chemical standard of purity was introduced for the first time and sufficient means were required to prevent the accumulation of more than nine volumes of carbon dioxide in 10,000 volumes of air

In 1906, protest from the operative weavers was renewed, a ballot taken showing a large majority in favour of abolition of steaming. Another Departmental Committee was then appointed with Sir Hamilton Freer-Smith, R.N., C.S.I., as Chairman, with more detailed terms of reference as follows :—

(1) What temperature and humidity are necessary in each case for the manufacture of different classes of cotton fabrics ;

(2) At what degrees of heat and humidity combined definite bodily discomfort arises, under the conditions of work carried on by the operatives, and what, if any, danger to health is involved by continuous work at those degrees ;

(3) What means of cooling humid sheds (where necessary) exist, whether combined with the means of humidifying or otherwise, which are both efficient and practicable, having regard to the conditions required for the manufacture of the several classes of goods ;

(4) What special arrangements, if any, are necessary in order to admit of the proper ventilation of dry weaving sheds without prejudice to the process of manufacture.

The principal recommendations contained in the final report of this Committee [6] may be summarised as follows :—

(*a*) The permissible relative humidity is defined in terms of the difference between the dry and wet bulb temperature. Below 70° F. this is limited to two degrees, and above 70° F. to an increased amount on a graduated scale.

(*b*) The introduction of humidity is prohibited when the dry bulb temperature is below 50° F. or the wet bulb temperature is above 75° F.

† Cotton Cloth Factories Act, 1897. (61 & 62 Vict. chap. 58). The Order was subsequently incorporated with slight modifications in the Factory & Workshop Act, 1901. (1 Ed. 7, chap. 22, Sec. 90–96).

(*c*) A standard of efficiency is prescribed for the material to be used for the lagging of steam pipes.

(*d*) With the object of lessening the quantity of steam introduced into the air, the standard of ventilation is relaxed from 9 volumes of carbon dioxide per 10,000 volumes to 8 volumes in excess of the outside air (roughly equivalent to 12 volumes absolute).

On the submission of this report, the same procedure was adopted as with the earlier Committee. A special Act was passed*, and under it the recommendations of the Committee were incorporated in a Statutory Order†, which is still operative.

This legislative action, however, like the previous statutes, failed to effect a complete settlement, and in 1914 Sir Hamilton Freer-Smith was engaged, on behalf of the Home Office in further discussions with the employers and operatives until postponement was brought about by the outbreak of war.

An interesting feature in the history of this question is the different aspects from which the factors of humidity, temperature and ventilation have been successively regarded. The earliest report [1], as is natural, is practically silent on the modern physiological views as to the effects of humidity and temperature, and it would appear that the recommendation as to increased ventilation was made solely with a view to replacing vitiated air by fresh, the aspect from which ventilation questions in those days were always regarded. Similarly, in the report [2] of Sir H. Roscoe's Committee, humidity is discussed chiefly from the point of view of deposit of moisture (on the clothing, etc.), and not from its physiological aspect. This is clearly indicated by the schedule of humidity recommended, in which wet-bulb temperatures up to 91° F. are specified, with the implication that work would be possible under those conditions. The report suggests, in short, that atmospheric humidity was regarded as of secondary importance compared with other matters, such as dust, purity of water and ventilation.

At the time when the third inquiry was held, more recent physiological work on the subject was available. Not only was general evidence given before them by Drs. J. S. Haldane, L. Hill, A. E. Boycott and M. S. Pembrey [5 221], but two important series of observations were made on behalf of the Committee on weavers actually at work. In the former of these [6 15], which was carried out by Dr. T. M. Legge in co-operation with the Medical Officers of Health of certain Lancashire Boroughs, a large number of mouth

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* The Factory and Workshop (Cotton Cloth Factories Act, 1911) (1 and 2 Geo. 5, chap. 21)

† Regulations for Cotton Cloth Factories, dated December 21, 1911.

temperatures were taken in weaving sheds, in which the wet-bulb temperature was 75° and over, both before the weaver had begun work and after he had been exposed to shed conditions for some hours. The two series, on being compared, clearly indicated that a rise in mouth temperature occurred in the later observations as compared with the earlier*. Dr. Legge's conclusion is as follows :—

> "The general conclusion I have formed from the detailed study of the observation is that a rise of mouth temperature makes itself distinctly felt when the temperature of the wet bulb exceeds 75° F ; in other words, that weavers are likely to be working under adverse physiological conditions."

The second inquiry, conducted by Drs. M. S. Pembrey and E. L. Collis [6 24], was of a more intensive character, and was based on detailed observations of mouth, rectal and skin temperatures, pulse rate, and blood pressure, made on the authors themselves and on certain weavers working under ordinary conditions. The inquiry led them to the following general conclusions :—

> "Our observations show that the influence of the warm, moist atmosphere is to diminish the difference between the internal temperature of the body and that of the peripheral parts The tendency is to establish a more uniform temperature of the body as a whole, and to throw a tax upon the powers of accommodation, which is indicated by the low blood pressure, notwithstanding the rapid rate of the pulse. This is exactly the condition which would explain the discomfort and low state of health of which many of the weavers complain. . . . .
>
> "In a weaving shed the machine sets the pace, and the worker must neglect the dictates of his sensations, which are the natural guardians of his health and well-being. He must strive, as far as possible, to accommodate himself to the adverse conditions of heat and moisture. Some workers can respond to the demand better than others, but all must have their powers of accommodation taxed when the temperature of the wet bulb rises much above 70° F. It is not surprising, therefore, that at the end of a day's work many of the weavers complain that they have no energy left, have no great desire for food, and need only drink and rest"

With this evidence before them, the Committee accepted the principle that of all the different factors operating, the most important is the wet-bulb temperature. Not only was their main recommendation concerned with definite limitation of wet-bulb temperature, but with the avowed object of retarding its rise, a relaxed standard of ventilation was put forward, thus reflecting the present views that wet-bulb temperature is of greater physiological importance than change of air.

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* In an inquiry on similar lines carried out by Legge in certain *linen* weaving sheds, in which the wet-bulb temperatures were higher, the rise in mouth temperature following exposures to shed conditions was found to be still more marked [7 41].

Such then was the position at the time when the Board was appointed (July, 1918), and amongst the earliest suggestions received by the Board was one from the Home Office calling attention to the need for further investigation into the conditions in weaving sheds in the cotton industry [8 [15]]. The Board thereupon decided to pay special attention to this industry, and since their inception investigations have been in progress (under the supervision of Mr. S. Wyatt) into various problems arising in the weaving section. The results of these investigations are only now available, and the present report, which deals with the atmospheric conditions in weaving sheds, is in some sense the logical continuation of the previous inquiries that have been held.

In effect, the report introduces for the first time into the study of this question in cotton weaving, a new and important factor in environment, namely, air *movement.* In recent years, largely through the work of Dr. Leonard Hill, it has gradually become realised that neither the dry nor the wet-bulb thermometer is *per se* an accurate criterion of the physiological effects of environment, but that, in addition to these, the rate of *movement* of the air must be taken into account. For instance, a (wet-bulb) temperature, which will prove insupportable in still air, may be borne without discomfort if the air in contact with the body is kept in a state of movement. An instrument (the kata-thermometer) has been devised by Hill, by which the total cooling effect of the air (depending on the dry and wet bulb temperatures and the air movement) can be measured directly, and the present inquiry is based on a large number of observations which have been made in this way.

The Board desire to direct special attention to certain important points which emerge from this investigation.

In the first place, it appears (so far as conclusions can be drawn from the investigation of sample factories), that in humid cotton weaving sheds the physical conditions of the workers' environment do not reach the standard which ought to exist, and which is, in fact, attained in other, though not in all, industries. The physiological effects of these conditions have already been explored in previous inquiries, the results of which go to show that long continued exposure may produce discomfort, and tend to a low state of health.

Further, in another report dealing with linen weaving [9], some evidence has been recently adduced which suggests that similar environmental conditions when sufficiently pronounced, may react upon the operative in such a way as to impair his productive efficiency. This is shown by the fact that when the wet bulb temperature reaches 73° F., efficiency falls, and since

the high temperature has physically a beneficial effect on the yarn, this can only be ascribed to the bodily discomfort felt and to the fatigue induced by working under such conditions. Similar evidence also has been recently obtained in the case of cotton weaving [10]

The present Report does not touch on the vexed question that has been so frequently raised but never finally disposed of, namely, whether these conditions, which undoubtedly cause discomfort, are productive of actual ill-health. No conclusive evidence on the subject has ever been obtained, and indeed the lack of any real information relating to it is emphasised by each of the Departmental Committees which have successively dealt with humidity in weaving. The possibility of studying this question by a determination of the actual sickness incidence in humid and dry sheds has already been before the Board, in consultation with the Home Office and the Trade, and at a conference with employers and operatives, held in Manchester in July, 1920, under the Chairmanship of Sir Hamilton Freer-Smith, the action contemplated was unanimously approved by those present. In view of this approval, the Board have made preliminary inquiry into the matter, and have arrived at the conclusion on the advice of the Committee on Industrial Health Statistics that owing to the absence of certain necessary information and to the abnormal conditions prevailing during the war, the use of existing sickness records for this purpose will not be practicable, and that an investigation therefore must be based on records kept in the future. Quite recently, further progress has been made and definite lines of inquiry which seem to offer the most promising prospects are now under consideration. Whilst it appears that actual investigation cannot usefully be started at the present time, the Board hope that when trade conditions again become normal the industry may be disposed to collaborate with them in future work on this subject, for which the expert advice of the Committee on Industrial Health Statistics will be available.

Secondly, the present report suggests two important methods by which improvement in the working conditions can perhaps be brought about. One of these is the use of more suitable clothing on the part of the operatives. Perhaps the most definite feature of the observations on weavers made by Dr. Legge and by Drs. Pembrey and Collis [6] is the consistently higher mouth temperature on the part of women as compared with that of men, and this is ascribed by the authors to the less suitable clothing worn by the former. The great importance of the kind of clothing worn on its bearing on comfort is perhaps not generally realised, and the attention of the industry is accordingly invited to the section in the present report dealing with this subject.

The other method is the introduction of some means for artifically increasing the air movement in the neighbourhood of

the operatives, on the lines of the experiments described on p. 30. The practical adoption of some such method was in fact foreshadowed in 1914 by a Departmental Committee dealing with the kindred process of linen weaving [7]. Referring to Dr. L. Hill's observations with the kata-thermometer, they state :—

> "He urges that in heated atmospheres, whether moist or dry, greater comfort can be secured by the use of appliances which will keep the air in continual motion, even where circumstances render it inexpedient to admit more than a limited amount of fresh air. In our opinion manufacturers might with possible advantage, and at little cost, give efficient trial to Dr. Hill's suggestion. This might be done by small fans placed on the heddle-bars of looms, or by fixing blades in suitable places on the revolving shafting."

A similar suggestion is contained in the Annual Report of the Chief Inspector of Factories for 1914 (p. 62), from which it even appears that appliances for increasing air movement have already been tried on a practical scale :—

> "Air samples taken when investigating complaints of impure air or of bad ventilation often gave quite satisfactory results upon analysis, and Mr Crabtree (Burnley) suggests that the cause of complaint is stagnant air, and not excess of carbon dioxide. As a remedy for this he suggests that agitators in the shape of flat boards (about 14 in wide and 10 in long) should be fitted to the overhead shafting, so that the air is made to circulate with their revolutions This plan has been successfully tried in three sheds in this district"

The Board are advised that the application of this principle is not free from practical difficulties. They understand, for instance, that the actual device described in the report is open to objection on the grounds that it interferes with the free movements of the weavers, and that other appliances suggested (such as the agitators already mentioned) could not be widely adopted without extensive structural alterations. Nevertheless, in view of the suggestive results embodied in this report, the Board think that unless and until it is found possible to dispense with artificial humidification through technical modifications in methods of manufacture (such as sizing), a solution of this question may be found in the control of air-movement. They accordingly hope that textile engineers and all concerned in the industry will bring their practical knowledge to bear on the subject, with the object of devising some means of improving the conditions physiologically without interfering with the process of manufacture, and of ascertaining, through experiments conducted on a larger scale than those described, how far such means are capable of general application.

REFERENCES

(1) Bridges, J H., and Osborn, E. H. (1884) : Report on the Effects of Heavy Sizing in Weaving on the Health of the Operatives Employed. (C. 3861)

(2) —— (1897) : Committee appointed to inquire into the Working of the Cotton Cloth Factories Act, 1889, etc. Report (C. 8348.)

(3) —— (1897) : Ditto ditto. Minutes of Evidence (C. 8349.)

(4) —— (1909) : Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds. Report (Cd. 4484)

(5) —— (1909) : Ditto ditto. Minutes of Evidence. (Cd 4485)

(6) —— (1911) · Ditto ditto. Second Report and Minutes of Evidence. (Cd 5566.)

(7) —— (1914) : Departmental Committee on Humidity and Ventilation in Flax Mills and Linen Factories. Report. (Cd. 7433)

(8) —— (1920) : Industrial Fatigue Research Board. First Annual Report. (*H M. Stationery Office*)

(9) Weston, H. C. (1922) : A Study of Efficiency in Fine Linen Weaving. (*Ind. Fat. Res. Bd. Report, No.* 20.)

(10) Wyatt S. (1922) : Variations in Efficiency in Cotton Weaving. (*Ind. Fat. Res. Bd. Report, No.* 23)

ATMOSPHERIC CONDITIONS IN COTTON WEAVING.

By S. WYATT, M Sc., *Investigator to the Board.*

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1. Introduction.

The practical study of human fatigue and efficiency must often depend to a large extent on technical considerations. For example, in a clothing factory the temperature of the air is a matter of small importance as regards manufacture, and attention can therefore be concentrated on securing ideal conditions for the workers. Again, in a steel works, although the high temperature required inside the furnace affects the environment of the worker, outside the furnace technique demands no special thermal conditions, and it is accordingly open to an investigator to consider every possible method of overcoming such effects of the manufacturing process as are physiologically undesirable. In other words, in both cases the investigator has a " free hand."

The textile industries, on the other hand (and particularly cotton), comprise certain processes in which the operatives during their work are continuously exposed to exactly the same extrinsic conditions as the material demands for successful manipulation. In dealing with such conditions, therefore, the exigencies of manufacture have to be taken into account and practical suggestions confined to those which will result in some physiological improvement without any seriously harmful technical effects.

The nature of the atmospheric conditions which prevail in cotton weaving sheds has up to the present been determined chiefly by means of wet and dry bulb thermometers. The Factory and Workshop (Cotton Cloth Factories) Act, 1911, gives the permissible maximum limits of humidity of the atmosphere for different temperatures, and the manager of a humid shed regulates the amount of artificial moisture entering the shed according to the readings indicated by these instruments.

The wet and dry bulb thermometers, however, fail to give a complete indication of the qualities of the air in the shed which affect the bodily comfort and efficiency of the operatives. Thus the temperature and humidity of still and moving air may be the same, but the " *cooling power* " will be very different in the two cases. A person who on a hot day in summer may be unpleasantly warm, can gain relief by a ride on the top of an open tram or bus. In the same way the unpleasant effects of a moist tropical climate can be greatly reduced by artificially creating air movement.

The bodily comfort of individuals is partially dependent upon the relations between the rates of heat production and heat loss, for if the former is in excess, discomfort is caused by the resulting accumulation of heat. A knowledge of the cooling effect of shed conditions upon the operatives is therefore important since unfavourable conditions probably accelerate the onset of fatigue and impair efficiency.

The human body may lose heat by the processes of convection, radiation, and evaporation. Normally, the first two processes are largely responsible for the maintenance of equilibrium between heat produced and heat lost, but during periods of bodily exertion, or under unfavourable atmospheric conditions, the mechanism subserving the last process is frequently brought into play in the form of sweating, whereby a considerable cooling effect is produced by the evaporation of superficial moisture, a fact which finds frequent application in the treatment of fever patients.

The cooling power of the air is most conveniently determined by the kata-thermometer,* a special form of thermometer so designed as to enable the time required for it to fall from one temperature to another to be accurately observed. From the time so required the rate of cooling of the bulb per unit area per second can be calculated by the use of a simple factor (the so-called "*kata factor*", depending on the size and shape of the bulb and marked on each instrument), and this in turn gives a direct indication of the cooling power of the surrounding air. By suitable adjustment of conditions the instrument can be made to measure its own rate of cooling (and accordingly the cooling power of the air) when its temperature approximates to that of the human body. Under such conditions the rate of cooling of the kata-thermometer gives an approximate indication of the rate at which the exposed surface of the human body loses heat. The instrument can be used either as a dry or wet bulb thermometer; in the former case it indicates the rate of heat loss due to the processes of radiation and convection (analogous to the state of the body when there is no visible perspiration), and in the latter it measures in addition the rate of heat loss due to evaporation (similar to the conditions when the body is visibly perspiring).

The cooling power of the air as measured by the dry kata (usually abbreviated into *dry kata cooling power*) depends upon :—

(*a*) The difference in temperature between the thermometer and the surrounding air.

(*b*) The rate of movement of air (" air velocity ").

---

* This instrument is the invention of Dr. Leonard Hill, F.R S., and is fully described in his book on " The Science of Ventilation and Open-Air Treatment, Part I " (*Medical Research Council, Special Report Series No.* 32). Most of the above remarks are based upon the contents of this book.

A description of the nature and use of the instrument is given in " Preliminary Notes on Atmospheric Conditions in Boot and Shoe Factories," by W. D. Hambly and T. Bedford (*Industrial Fatigue Research Board, Report No* 11), and in the Appendix to this Report (p 34)

A full account of the method of determining cooling power and air velocity is given in the Appendix to this Report. (p. 34.)

The cooling power of the air as measured by the wet kata (or *wet kata cooling power*) is a function not only of the temperature and air velocity, but also of the difference between the vapour pressure of the air saturated at body temperature (97·7° F.), and that of the air at the observed temperature.

According to Hill, the minimum cooling powers required for the comfort of those engaged in sedentary work are 6 for the dry kata and 18 for the wet; for weaving the values would be a little higher. These are henceforth referred to in the report as "*cooling standards*."

2. Methods of Observation.

Kata readings were taken during summer and winter in a number of humid sheds. The observations were spread over a number of days in each shed, since in the English climate the weather usually associated with the different seasons is notoriously uncertain. Although precautions were taken to secure typical seasonal readings, the summer was unusually cool and wet and the shed temperatures did not reach the usual level.

To avoid any preponderance of readings at any given hour, the observations were evenly distributed throughout the working day. Variations in method will be mentioned as they arise.

3. Description of Sheds.

The chief features of the sheds included in this investigation are given in Table I.

TABLE I.—*Description of sheds investigated.*

Shed.	Looms.	Operatives.	Capacity (cub. ft.)			Class of Work	Method of Humidifying	Method of Ventilation.
			Total	Per Loom	Per Operative			
A	1,134	320	838,890	740	2,621	Dhooties	Vortex	Vortex.
B	300	90	214,728	716	2,386	Shirtings	Steam Jet	Gregson's Fans.
C	609	250	288,458	474	1,154	Bleaching Goods.	Vortex	Vortex
D	2,020	886	1,236,704	612	1,396	Shirtings	Harts	Roof Doors.
E	417	118	308,890	741	2,618	Shirtings	Harts	Windows.
F	894	135	794,474	889	5,885	Printers and Sheetings.	Hall and Kay	Hall and Kay and Grids.
G	1,058	150	731,808	691	4,879	Printers and Twills.	Hall and Kay.	Hall and Kay.
J	835	260	453,096	543	1,743	Drills	None	Gregson's Fans.

4. Results Obtained.*

A.—Winter Observations.

(a) *Intermittent Series.*

In order to obtain results representative of the atmospheric conditions in humid weaving sheds during the winter months, observations of the cooling power of the air at head level were made in several sheds at different times of the day on different days. The results are given in Table II.

TABLE II.—*Atmospheric observations made in weaving sheds during winter.*

Shed	Observations	Temperature (° F) Dry Bulb	M V	Wet Bulb	M V	Cooling Power Dry Kata	M V	Wet Kata	M V	Cooling due to Evaporation ‡	Air Velocity (ft per min).
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A	40	70 7	2 5	65 8	2·5	5 4	0·6	15 8	1 2	10 4	32
B	27	65 5	2·3	62 2	1·7	6 2	0·5	17·7	1·3	11·5	26
C	43	72·9	1·9	68·7	1 8	4·7	0·4	14 9	1·1	10 2	24
D	18	69·1	2 0	63·7	1 5	5·4	0·3	13 3	0·9	7 9	24
E	30	70·9	1·6	65·5	1·6	5·2	0·4	13·1	1·0	7 9	28
Av † A–E	—	69 8	—	65 2	—	5·4	--	15 0	—	9·6	27
F	44	71·6	2·2	64 6	3·2	4·9	0·5	16·3	1·3	11 4	23
G	45	74·3	1·4	71 1	1 3	4 3	0·3	13·2	0·6	8·9	21

* The mean variation (M V) (cols 4, 6, 8, 10) is the average of the deviations of the individual determinations from their average, and is a measure of the degree of "scatter" of the individual measurements about their mean

† Sheds A to E are averaged separately for comparison with Table V later

‡ The "cooling power of the air due to evaporation" (col. 11) is obtained by finding the difference between col 9 and col 7 Recent experiment has shown that this difference is only an approximate measure, since under similar external conditions the surface temperatures of the dry and wet kata are not the same.

The average dry bulb temperature ranges from 65·5° F. in Shed B to 74·3° F. in Shed G.

The results show that with the exception of Shed B the average never reaches the dry kata cooling power standard of six, even during the winter months when the shed temperatures are comparatively low. The conditions in Shed G are particularly unfavourable, the relatively high temperature and slight movement of the air producing an average dry kata cooling power of only 4·3. Similarly, the average wet kata cooling power never reaches the standard (18) considered necessary for sedentary workers, though it approaches it very closely in Shed B (average 17·7). In this respect Shed G is again one of the most unsatisfactory (average 13·2). Here the investigator experienced great discomfort and on several occasions perspired freely. Similar

* The writer is indebted to Miss P. M Vickers, Miss B S McFie, Mr H C. Weston and Mr A. D. Ogden for the collection of the data contained in this report.

signs were also noticeable in the case of the operatives, whilst in Sheds A, B, C and F the skin of the weavers did not show visible perspiration.

The effect of different degrees of humidity is seen in a comparison of the results of Shed G with those of Shed F. The higher wet kata cooling power and evaporative power in the latter shed are due almost entirely to the lower humidity as indicated by the greater difference between the wet and dry bulb thermometer readings.

A dry kata cooling power of five and a wet kata cooling power of 15 are apparently sufficient to prevent sweating on the part of weavers employed under normal conditions, but the air under these conditions is rather stagnant and lacks the stimulating effect usually associated with pleasant external conditions, and higher values are undoubtedly desirable.

In general, the results obtained in the different sheds show that the cooling power of the air becomes distinctly unsatisfactory when the shed temperature exceeds 70° F. For higher temperatures, a satisfactory cooling power can only be obtained by increasing the rate of air movement.

Considerable differences in cooling power exist in the different sheds. Since all the sheds are exposed to fairly similar outside atmospheric conditions, the shed temperatures and humidities, and consequently the cooling power of the air in the sheds, are, within limits, under the control of the management, and the differences observed are largely due to the different quantities of steam admitted into sheds for humidification purposes.

The dry kata observations have been also arranged according to the frequency with which the values fall within certain limits, although it must be admitted that the number of observations comprised within each class interval is generally small. Fig. 1 shows the distribution of the dry kata observations according to cooling power values. Thus in Shed A, the number of readings for successive increases of 0·5 were :—

From	Number.
3·5 — 4·0	1
4·0 — 4·5	3
4·5 — 5·0	8
5·0 — 5·5	13
5·5 — 6·0	5
6·0 — 6·5	6
6·5 — 7·0	3
7·0 — 7·5	1

A broad flat curve means that the readings cover a wide range and that the number of readings at one part of the curve is not very different from the number at any other part. A narrow tall curve (*e.g.*, Shed G) indicates a small range and a tendency for most of the readings to cluster around the average.

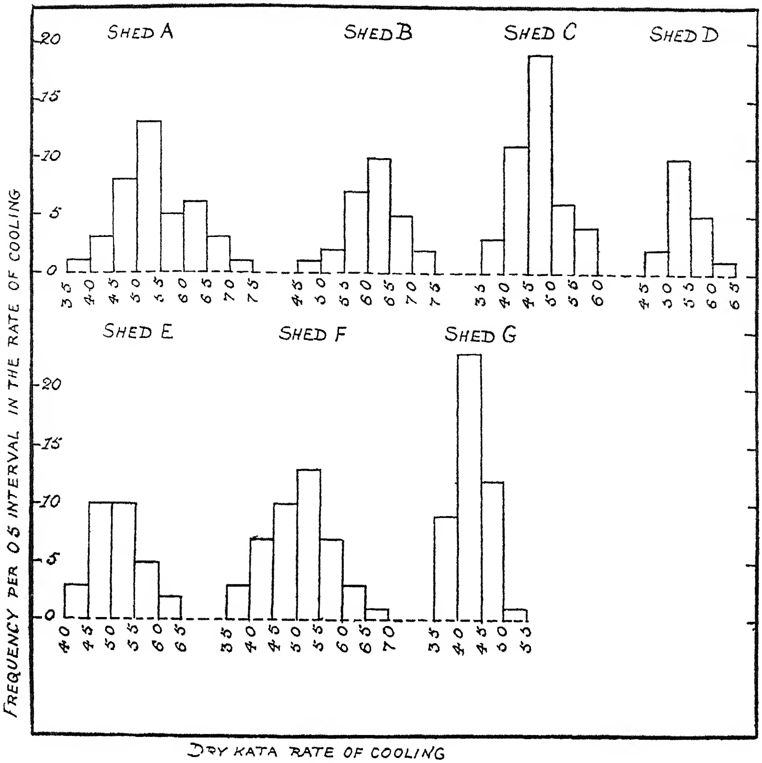


FIG 1.—DISTRIBUTION OF DRY KATA READINGS ACCORDING TO COOLING POWER (WINTER RESULTS)

The curves in general show that the individual readings are fairly regularly distributed about a point which approximates to the average values given in Table II. A larger number of readings in each shed would give curves which approximate to the normal curve of distribution. The deviation of the results from the average is given numerically in Table II by the mean variation (M.V.), and the curves show that this quantity is not unduly influenced by unusually high or low readings. The uniformity of the results obtained in Shed G is largely due to the unusually uniform temperature which prevails in this shed during the working week.

(*b*) *Continuous Series.*

In order to determine the variations in cooling power during the hours of work, continuous observations were made in three sheds on different days. In each shed a representative position at head level was chosen for the observations and maintained throughout each series of readings. The results obtained are given in Table III.

TABLE III.—*Record of observations made at approximately hourly intervals during hours of work.*

Approximate Hour.	Shed A. (Average for 4 days)										Shed D (Average for 2 days)						Shed E (Average for 3 days)					
	Temperature.				Cooling Power				Cooling due to evaporation.	Air velocity (feet per min)	Temperature		Cooling Power		Cooling due to evaporation	Air velocity (feet per min)	Temperature		Cooling Power		Cooling due to evaporation	Air velocity (feet per min)
	Dry Bulb.	M V	Wet Bulb	M V	Dry Kata	M V	Wet Kata	M V			Dry Bulb	Wet Bulb	Dry Kata	Wet Kata			Dry Bulb.	Wet Bulb	Dry Kata	Wet Kata.		
8 0	58·5	3·8	56·1	3·2	7·7	0·8	19·2	1·2	11·5	28	61·0	56·9	7·2	17·1	9·9	29	60·4	55·3	7·2	18·7	11·5	26
9 0	62·8	2·7	59·0	2·9	6·8	0·7	16·9	0·7	10·1	28	63·5	59·7	6·5	16·0	9·5	25	64·9	60·8	6·2	15·4	9·2	25
10 0	65·6	1·4	62·1	1·1	6·1	0·3	16·1	0·5	10·0	27	65·4	61·8	5·8	15·4	9·6	19	67·1	62·7	5·6	15·1	9·5	21
11 0	66·9	0·5	62·5	1·3	5·8	0·3	15·7	0·1	9·9	24	66·7	62·4	5·5	15·1	9·6	18	68·9	64·5	5·4	14·9	9·5	23
12 0	67·6	0·9	62·7	0·9	6·0	0·5	16·4	0·4	10·4	31	68·2	63·4	5·2	14·7	9·5	17	71·0	66·2	4·9	15·1	10·2	21
12 30	66·9	0·9	61·7	1·4	5·9	0·5	16·4	0·4	10·5	26	67·8	61·3	5·5	16·0	10·4	21	69·1	63·0	5·8	17·3	11·5	34
1 0	65·1	0·7	60·1	1·4	6·2	0·5	17·6	0·3	11·4	25	65·5	59·9	5·7	15·7	10·0	18	67·1	61·4	6·6	17·3	10·7	44
1 30	65·5	0·5	61·4	2·0	6·3	0·4	17·1	0·6	10·8	29	66·9	62·0	5·4	15·8	10·4	17	—	—	—	—	—	—
2 0	—	—	—	—	—	—	—	—	—	—	68·9	64·5	5·1	14·5	9·4	18	70·9	65·5	5·0	14·1	9·1	23
2 30	66·4	1·6	61·9	1·4	6·1	0·3	16·3	0·2	10·2	28	—	—	—	—	—	—	—	—	—	—	—	—
3.0	—	—	—	—	—	—	—	—	—	—	70·5	66·0	4·7	13·8	9·1	16	73·0	68·1	4·5	13·3	8·8	20
3.30	67·4	1·6	63·5	0·9	6·1	0·4	16·7	0·3	10·6	32	—	—	—	—	—	—	—	—	—	—	—	—
4 0	—	—	—	—	—	—	—	—	—	—	71·0	66·6	4·5	14·1	9·6	14	74·2	68·4	4·5	13·7	9·2	25
4 30	66·9	1·4	62·8	0·9	6·1	0·3	16·2	0·4	10·1	30	—	—	—	—	—	—	—	—	—	—	—	—
5 0	—	—	—	—	—	—	—	—	—	—	72·3	67·4	4·4	13·8	9·4	16	75·1	68·9	4·4	13·6	9·2	28
5 30	66·4	1·4	61·4	1·4	6·4	0·5	16·2	0·9	10·2	38	—	—	—	—	—	—	—	—	—	—	—	—

The mean variations for Sheds D and E are not given, but they are of the same magnitude as those for Shed A

The general tendency of these results is seen more clearly in Figs. 2, 3 and 4. Usually, the dry kata cooling power decreases during the morning spell, rapidly at first but more slowly afterwards. With the cessation of work at 12.15 p.m., a rise takes place, which continues during the dinner hour, but after the resumption of work at 1.15 p.m., there is a gradual fall throughout the afternoon spell, until preparations for departure are made just before 5.30 p.m.

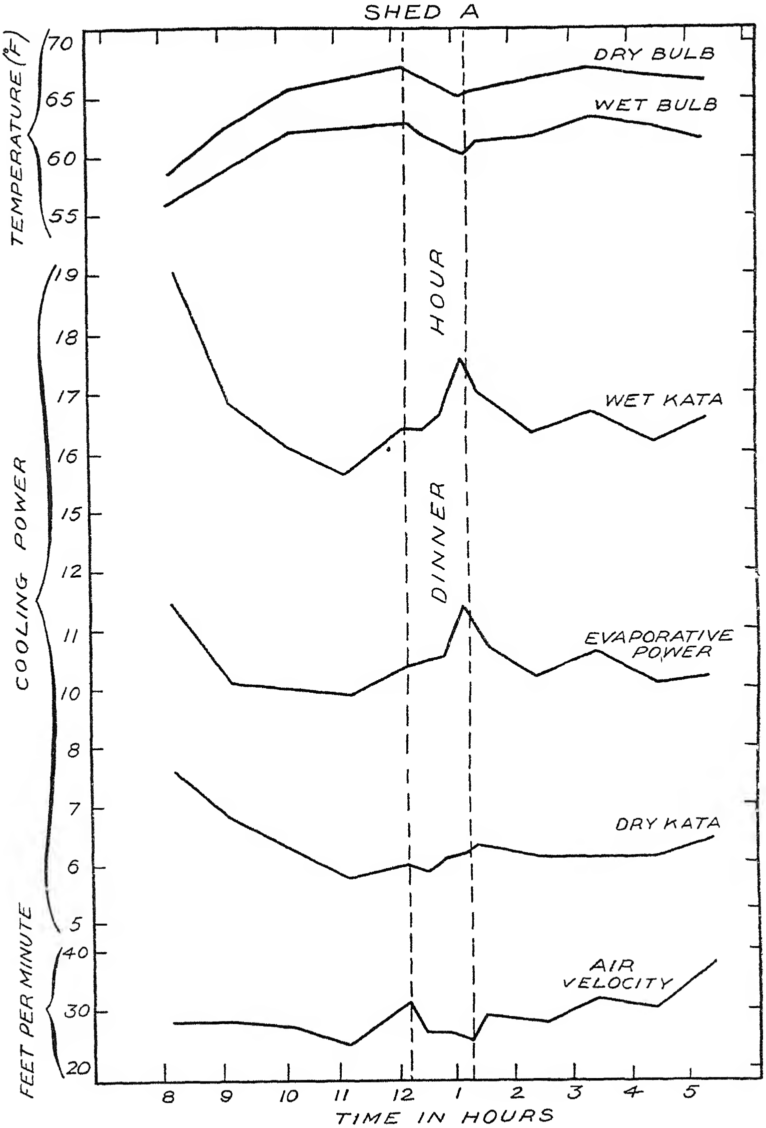


FIG 2 VARIATIONS IN TEMPERATURE AND COOLING POWER OF AIR

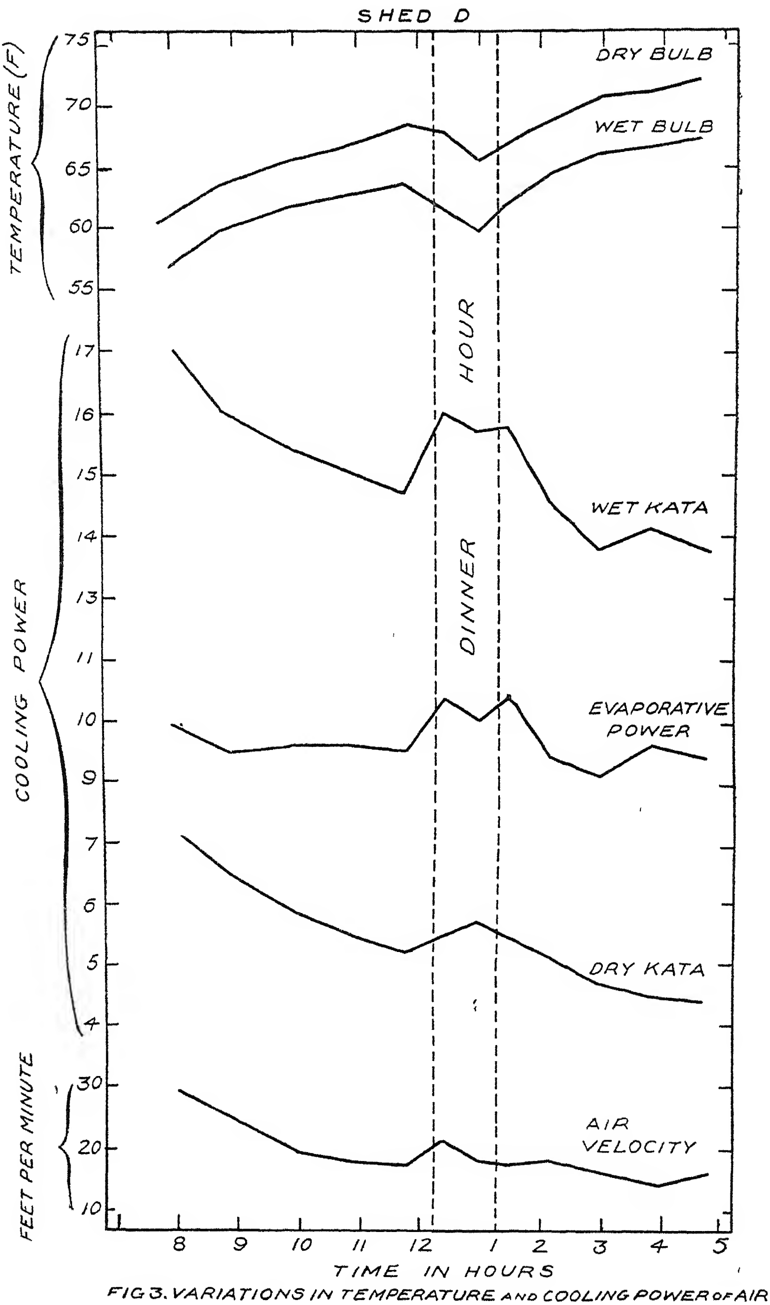
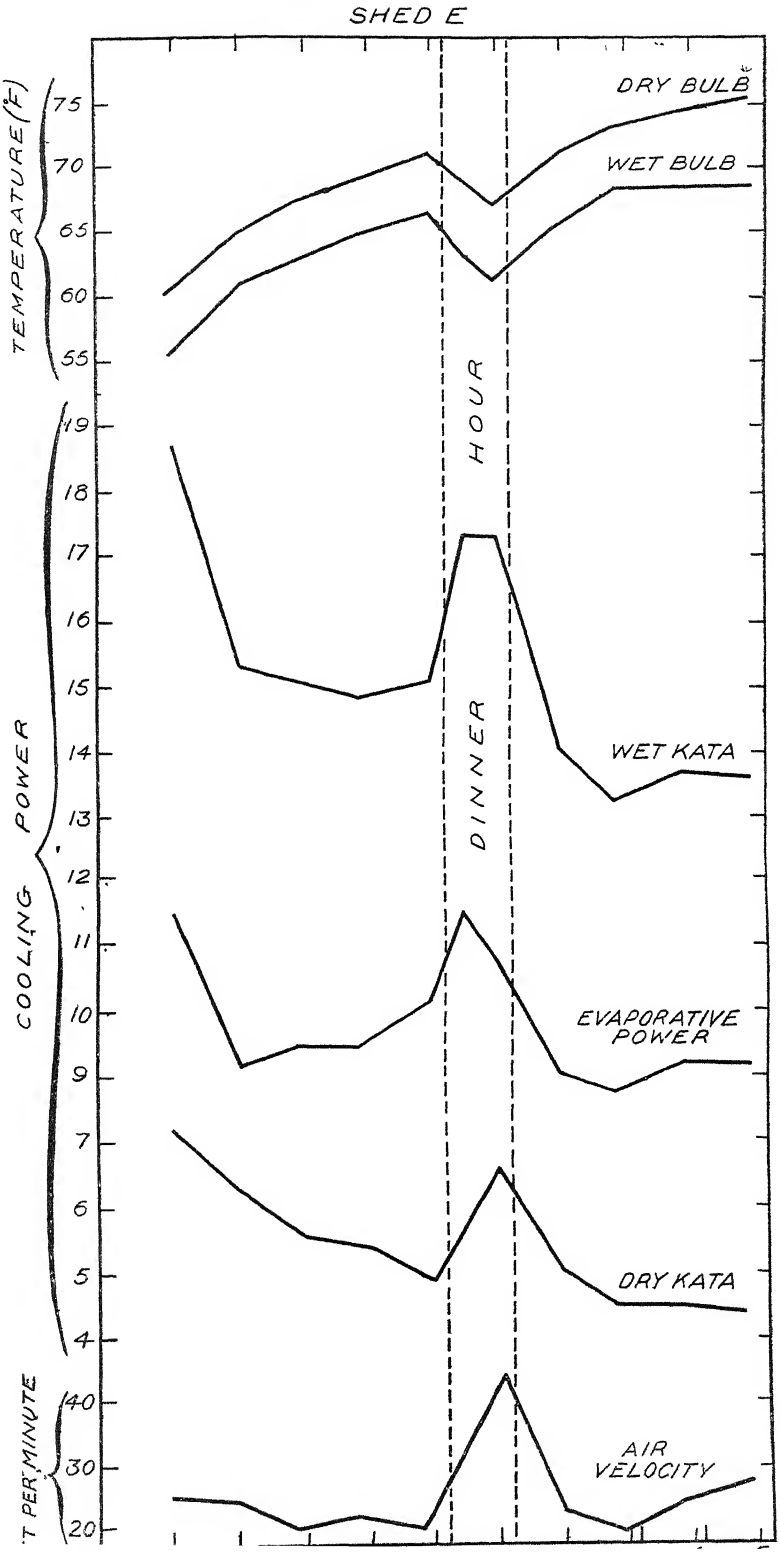


FIG 3. VARIATIONS IN TEMPERATURE AND COOLING POWER OF AIR


SHED E
TEMPERATURE (°F)
75
70
65
60
55
DRY BULB
WET BULB
HOUR
DINNER
COOLING POWER
19
18
17
16
15
14
13
12
11
10
9
7
6
5
4
WET KATA
EVAPORATIVE POWER
DRY KATA
PER MINUTE
40
30
20
AIR VELOCITY

In explaining the above tendency, we must remember that the rate of cooling of the dry kata is dependent upon (1) the temperature of the air, and (2) the rate of air movement. During the normal period of work (*i.e.*, omitting the first and last observations and the meal hour), the temperature rises steadily throughout the day. On the other hand, for a given shed the air velocity remains remarkably constant, hence we should expect the continuous decrease in cooling power that actually occurs in most sheds, since the rise in temperature is not counteracted by an adequate increase in air velocity. The only exception is the afternoon spell of Shed A, in which the cooling power remains virtually constant corresponding with a nearly constant temperature, due probably to adjustment of the heating appliance in the shed, since in winter the sheds are artificially heated by steam pipes, so that the control of the inside temperature is to some extent in the hands of the management.

During the meal hour, other factors come into operation, for instance :—

(*a*) the machinery is stopped and most of the operatives are absent. The mechanical energy used and the bodily heat of the operatives are responsible for most of the heat produced and the consequent rise in temperature. With the removal of these two sources of heat, the temperature rapidly falls;

(*b*) the ventilating system is stopped, which with the absence of moving machinery, *reduces* the rate of air movement;

(*c*) doors are continuously being opened whereby the rate of air movement is *increased*.

All of these are reflected in the curves. In each shed there is an abrupt drop in temperature. The extent to which this influences the dry kata cooling power depends on the relative importance of the second and third factors. In the large Sheds A and D, the third has a very small effect, so that the air velocity actually diminishes and the increase in cooling power is due entirely to the fall in temperature. In the small Shed E, however, the opening of doors causes an appreciable increase in air velocity, and the rise in dry kata cooling power is much greater. Similar considerations hold in regard to the beginning and the end of the day's work.

In regard to the properties affected by humidity, the wet bulb temperature follows a course closely parallel with the dry bulb temperature, indicating an almost constant difference between the two, though this difference is increased during the meal hour and generally at the beginning of work as well. Similarly, the wet kata cooling power follows a course similar to that of the dry kata cooling power, but the gradients are steeper. The evaporative

cooling power is more constant, except at the beginning of the day, and during the meal hour, when the amount of humidity in the shed atmosphere is below its normal level.

The data for the three sheds show certain differences. A dry kata cooling power of six is attained and maintained only in Shed A. In Sheds D and E it falls as low as 4·5 in the afternoon period. A cooling power of five did not appear to make the operatives sweat visibly. Thus in this respect winter conditions in weaving sheds cannot be said to overtax the body by the continuous use of the sweating mechanism. Greater bodily comfort would, however, result from the maintenance of atmospheric conditions having a higher cooling power; moreover, the body heat production is promoted by higher cooling powers and this is accompanied by better appetite and improved vigour and health.

The conditions in Shed D are less variable than those in Shed E. This is probably due to the fact that Shed D is one of the largest in the cotton industry, while Shed E is comparatively small. Shed A is intermediate in size between D and E. An external force acting upon large masses has much less effect than upon small, and a current of air entering large and small sheds will have a similar influence. Thus movements of the operatives and doors which modify air movements in the small Shed E fail to have any appreciable effect upon the air in the large Shed D.

Except during the first hour of the day the wet kata cooling power (like the dry kata) is much below the standard of 18 recommended for sedentary workers.

Again, in comparing the air velocities, we find considerable differences in the three sheds. During the normal period of work, A has an air velocity of about 28 feet per minute, D of 18, and E of about 23. This suggests that A is better ventilated than E, and E than D.

A general comparison of the sheds investigated shows in fact that the conditions prevailing in Shed A are the most favourable and in Shed D the least. The decreased cooling power in the latter is due almost entirely to the stagnant nature of the air, and this again is the result of the exceptionally large dimensions of this shed. Some means of increasing the air movement in large sheds seems to be specially needed in the interests of the bodily comfort of the operatives.

(c) *Extended Series.*

At one of the mills included in this investigation (Shed A) kata readings were taken in the same position at the middle of the morning and afternoon spells (*i.e.*, at 10 a.m. and 3.15 p.m.)

on every working day during the winter months. The morning and afternoon averages for each week are given in the following table : —

TABLE IV.—*Record of atmospheric conditions in a weaving shed during consecutive weeks in winter.*

Week Ending	Temperature (° F)				Cooling Power				Cooling due to Evaporation.		Air Velocity (ft per min)	
	Dry Bulb		Wet Bulb		Dry Kata.		Wet Kata					
	a m.	p m.	a m	p m	a m	p.m	a.m	p m	a m	p.m.	a m	p m
Nov 1 ..	67 2	69 6	65 5	67 6	5 9	5 4	15 2	14 1	9·3	8·7	27	26
Nov 8 ..	66 4	68 6	64 7	66 6	6·2	5·4	14·7	14 7	8 5	9·3	30	22
Nov 15 ..	62 6	66·5	61 2	64·3	7 0	6 4	16 4	15 9	9 4	9 5	31	36
Nov. 22 .	66 9	67 8	65 6	65 5	5 9	5 6	15 5	15 8	9·6	10 2	26	23
Nov 29 .	66 1	68 4	64 7	66 1	6 3	5 8	15·5	15·4	9·2	9·6	31	30
Dec. 6 ..	66·7	68 1	65 0	65 6	6 0	5 6	15 2	14 6	9 2	9 0	28	24
Dec 13 .	64 7	68 2	63 2	65 6	6 5	6 1	15 7	15 2	9 2	9·1	29	36
Jan. 10 ..	65 2	68 2	63 9	66 6	6 2	5 7	15 8	15 6	9 6	9 9	25	27
Jan 17 .	66·7	68·2	64 9	65 7	5 9	5 8	15 3	15 1	9 4	9 3	25	29
Jan 24 .	65 9	68 1	64 1	65 5	6 5	6 0	16·7	15 6	10 2	9 6	33	33
Jan 31 .	63·6	66 7	61·1	63 9	6·5	6 3	16 7	16 4	10 2	10 1	25	34
Feb. 7 .	67 0	68 7	64 6	64 5	5 8	5 7	16 1	16 1	10 3	10 4	24	30
Feb 14 .	66 2	67 2	64 1	64·5	5 9	5 5	15 9	15 7	10 0	10 2	21	20
Average ..	*65·8*	*68 0*	*64 0*	*65 5*	*6·2*	*5 8*	*15 7*	*15·4*	*9 6*	*9 6*	*28*	*28*
M.V... .	1 1	0 6	0 9	0 8	0 3	0 2	0 5	0 5	0 4	0 4	—	—

In cooling power of the air this shed is one of the best of those investigated, and the dry kata cooling power at the times stated is approximately equal to the standard of six. The wet kata cooling power is evidently affected by the high humidity of the air caused by the introduction of steam and falls short of the standard (18) by approximately 2·5.

Since in this shed the average dry kata cooling power of six corresponds with an average dry bulb temperature of 66·9° F, it follows that for the maintenance of the standard of six either the temperature of the shed must never exceed 66·9° F, or the movement of the air must be increased. In the same way the corresponding limits of temperature for other sheds can be determined.

The results also show that in the morning conditions are slightly more favourable than in the afternoon, a fact which is due chiefly to the lower morning temperature.

The variability in the weekly averages as shown by the mean variation, is remarkably small, and emphasises the uniformity of the atmospheric conditions prevailing at the same time of the day in a humid weaving shed during the winter months.

The air movement was quite imperceptible, and failed to produce the stimulating effect which is noticeable under more pleasant conditions outside. Though the operatives appeared to be content and showed no signs of bodily discomfort, beneficial results would probably be obtained if the cooling power and stimulating effects of the air were increased by air movement.

B. Summer Observations.

(a) *Intermittent Series.*

Observations on the rate of cooling of the kata thermometer were made at different times on different days during the summer months and the results obtained are given in Table V.

TABLE V.—*Record of atmospheric conditions in weaving sheds during the summer months.*

Shed	Ob-serva-tions	Temperature (° F).				Cooling Power				Cool-ing due to Eva-pora-tion.	Air Velo-city (ft per min)
		Dry Bulb	M V	Wet Bulb	M.V	Dry Kata	M V.	Wet Kata	M V		
A	33	72·7	2·8	68·7	2 6	4·7	0·6	14·2	1·1	9·5	24
B	22	77·5	2 1	73·4	1 4	3·8	0·5	12·7	0·9	8·9	24
C	33	76 1	2·2	71·8	1·6	3·9	0·4	13·4	0·8	9·5	19
D	24	75·3	2·9	67·8	2 4	4·7	0·7	13 6	1·3	9·3	39
E	20	71 3	3·0	64·8	1·9	4·7	0 6	14 1	0·8	9 4	18
Av A–E	—	74·6	—	69·3	—	4·4	—	13 6	—	9·3	25
X	31	75 5	1 5	73·3	1·2	4 3	0·3	12·0	0·9	7·7	27
J	24	72·1	2·1	62·8	1·3	5 0	0·5	17·3	1 2	12·3	28

In considering these results it must be remembered that the summer of 1920 was unusually cool and wet, so that the shed temperatures were lower and the rates of cooling of the dry kata correspondingly higher than the average. From this point of view the observations were made under exceptionally favourable summer conditions and must be interpreted accordingly.

Taking Sheds A to E, for which both winter and summer readings are available, the results show that the average dry bulb temperature at the time of the observations was 74·6° F. in summer, or 4·8 degrees higher than the corresponding temperature for the winter months. The average wet bulb temperature was 69·3° F., or 4·1 degrees higher than the average for the winter months. Thus the difference between the wet and dry bulb temperatures for the winter readings was slightly less than for the summer, though well outside the limit specified (3·5 degrees at a dry-bulb temperature of 75°) in the Cotton Cloth Factory Act of 1911.

The effect of the higher summer temperature upon the rate of cooling of the dry kata is distinctly noticeable; this varies from 3·8 in Shed B to 4·7 in Sheds A, D and E, and the average for Sheds A to E is 4·4, or 1·0 less than the corresponding value

for the winter months. Thus the rate of cooling of the dry kata during the summer months is considerably below the standard (6·0) suggested by Hill.

The average rate of cooling of the wet kata in the same sheds is 13·6, as compared with 15·0 for the winter months. This again is much below the standard suggested (18·0), an indication that the normal rate of evaporation of moisture from the body is retarded by the atmospheric conditions in the shed. Air with such low evaporative power is slow to absorb superficial moisture caused by sweating, with the result that the operatives tend to become overheated and decidedly uncomfortable.

During the hot summer months complaints about the high shed temperatures are very numerous and the appearance of the operatives together with the kata readings fully justify these complaints. In another report the effect of atmospheric shed conditions upon efficiency will be considered, but the more important question of their relation to the general health and physical fitness of the operatives, in spite of the work already carried out on the subject, still calls for further study. At this stage it is sufficient to point out that during the summer months the operatives in humid weaving sheds are working under decidedly unnatural and unfavourable conditions, and any devices which will reduce the effects of a high temperature and degree of humidity without seriously impairing productive efficiency should be given a trial, and adopted whenever possible.

Shed J differed from the other sheds in the fact that it was "dry"; *i.e.*, the air in it was not humidified by artificial means. This difference is reflected in the higher wet kata cooling power (17·3) and evaporative power (12·3), as compared with 13·6 and 9·3 for the humid sheds. The temperature also is moderate and the rate of cooling of the dry kata in consequence greater than the corresponding results obtained in the other sheds, but the greatest difference is in the evaporative power.

The higher cooling power in Shed J means that the operatives in this shed will lose heat more readily than those in the other sheds. Sweating will not be so active, since the superficial body moisture will evaporate more rapidly and consequently produce a greater cooling effect. In this respect a "dry" shed is more conducive to bodily comfort than one in which additional moisture is introduced, though the beneficial effects of a greater rate of cooling may be partially neutralised by the effects of atmospheric dust, which is a prominent feature in many dry sheds.

The frequency of occurrence curves (Fig. 5) are constructed in the same way as those for the winter readings, but since they are based upon comparatively few readings they give only an approximate indication of the distribution of the observations obtained from each shed. This distribution appears to approach the normal or symmetrical curve in every case, and a larger number of observations would undoubtedly give such a curve.

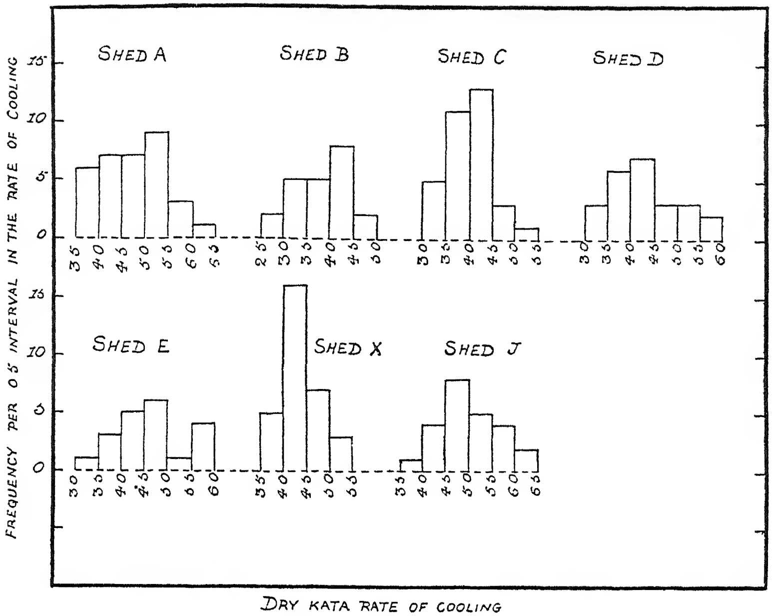


FIG 5—DISTRIBUTION OF DRY KATA READINGS ACCORDING TO COOLING POWER (SUMMER RESULTS).

(b) *Continuous Series.*

Kata readings were taken at approximately hourly intervals on four successive days in shed X and the averages of the results obtained at corresponding times are given in the following table :—

TABLE VI.—*Record of atmospheric observations made at approximately hourly intervals during the hours of work in Shed X (Summer.)*

Mean Time	Temperature (° F)		Cooling Power		Cooling due to Evaporation.	Air Velocity (ft per min).
	Dry Bulb.	Wet Bulb	Dry Kata	Wet Kata		
9·25	72 9	71·6	5·1	13·8	8·7	38
10·18	73·9	72·2	4·7	13 1	8·4	29
11·15	74·5	72·3	4 4	12·3	7·9	25
12·2	75·0	72·8	4·3	12 0	7·7	25
1·55	75·3	73·2	4·4	11·8	7·4	29
2·53	76·7	74·3	4·2	11·1	6·9	31
3 51	77·5	75·0	4·0	10·9	6·9	30
4·50	77·9	75·1	4·0	11·2	7·2	31

The above results are represented graphically in Fig. 6.

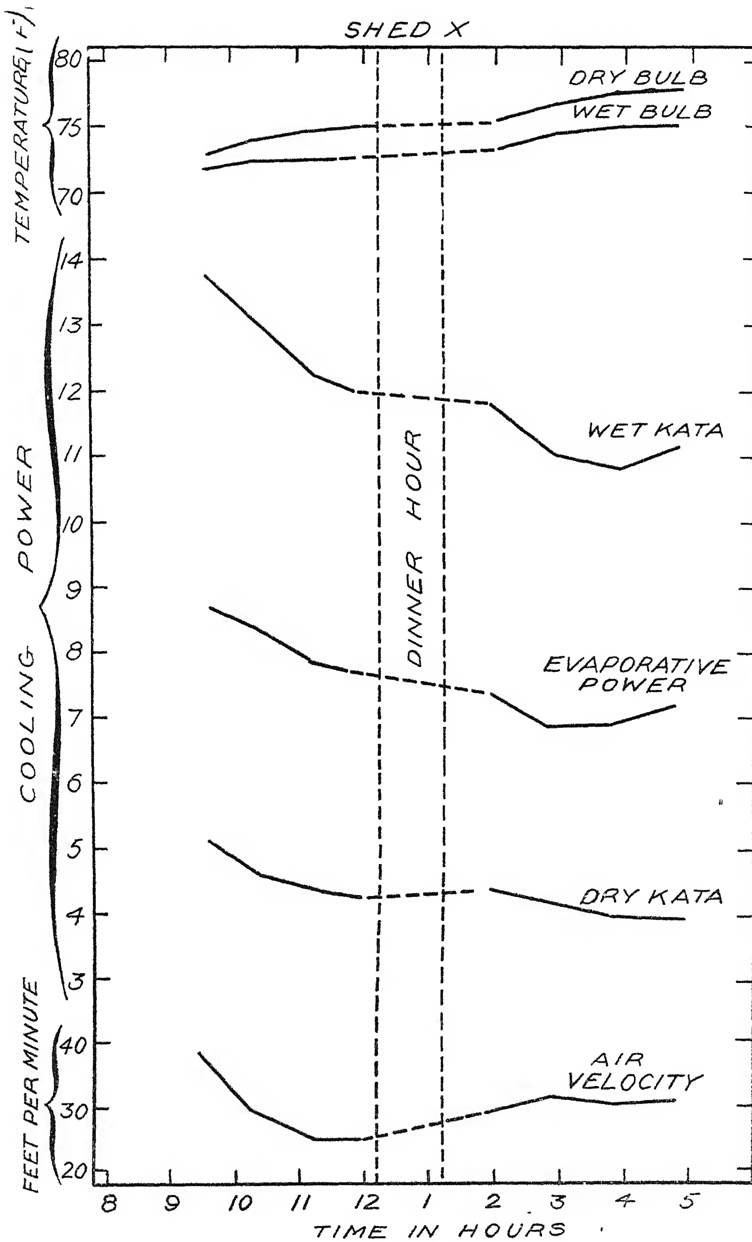


FIG. 6. VARIATIONS IN TEMPERATURE AND COOLING POWER OF AIR

The general direction of the above curves is very similar to those obtained for the winter months, but the rise in cooling power during the dinner hour, which is characteristic of the winter readings, is not shown because observations were not taken at that time. Thus the wet and dry bulb temperatures rise steadily throughout the working day and corresponding falls are seen in the wet and dry kata readings.

These results show that as regards rate of cooling, the atmospheric conditions are unsatisfactory when work is begun and become progressively worse as the day proceeds. Such conditions may be favourable to the yarn used in the weaving process, but they are unfavourable to the operatives, for they throw a strain on the heat-regulating mechanism of the body and so undoubtedly accelerate the onset of fatigue. In this shed, also the degree of humidity is exceptionally high and the wet kata cooling power is accordingly less than usual. For the same reason the evaporative power of the air is comparatively low, a state of affairs which will accentuate the effects upon the warp and the weaver just mentioned.

(c) *Extended Series.*

Kata readings were taken at 10.30 a.m. and 3.0. p.m. on consecutive working days for a period of nine weeks in Shed A, and the averages for each week are given in Table VII. All the readings were taken in the same position and they are typical of the atmospheric conditions prevailing in this shed during the earlier part of the summer of 1920.

TABLE VII.—*Atmospheric conditions during consecutive weeks in summer in a weaving shed.*

Week Ending	Temperature (° F.)				Cooling Power				Cooling due to Evaporation		Air Velocity (ft. per min.).	
	Dry Bulb		Wet Bulb		Dry Kata		Wet Kata.					
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
April 24	64·4	68·3	61·9	65·6	5·9	5·1	18·1	16·0	12·2	10·9	19	15
May 1	63·4	68·9	60·9	66·3	6·0	4·9	17·4	14·9	11·4	10·0	17	14
May 8	66·7	69·3	64·4	66·7	5·8	5·0	16·9	16·3	11·1	11·3	23	15
May 15	67·5	73·9	64·3	71·2	5·6	4·4	16·8	15·1	11·2	10·7	22	22
June 5	67·0	74·5	64·9	71·9	5·5	4·0	16·4	14·0	10·9	10·0	19	15
June 12	68·5	74·2	66·7	70·8	5·4	4·2	16·9	15·1	11·5	10·9	23	19
June 19	71·8	77·4	68·3	71·8	4·6	3·5	14·6	13·6	10·0	10·1	18	15
June 26	72·7	78·6	68·8	74·2	4·4	3·0	14·6	12·1	10·2	9·1	17	16
July 3	72·1	77·5	68·2	72·9	4·3	3·6	14·6	13·6	10·3	10·0	13	18
Average	68·2	73·6	65·3	70·1	5·3	4·2	16·2	14·5	10·9	10·3	16	16
M.V.	2·7	3·2	2·3	2·6	0·6	0·6	1·1	1·1	0·6	0·5	—	—

These figures show the general decrease in the dry kata cooling power during the successive weeks. This decrease is, of course, caused almost entirely by the corresponding increase in the temperature of the shed. During the earlier part of the period under consideration, the rate of cooling of the dry kata in the morning spells approximates to the standard suggested (6), but later it falls much below this value. The rate of cooling in the afternoon is much lower than in the morning spells—a result which again is largely due to the higher afternoon temperature. During the afternoons of the last three weeks the cooling power is especially low (average 3·4), and in a typical summer it would be still less.

The variations in the wet kata cooling power are very similar and emphasise the fact that the evaporative power of the air is unable to give the relief which is advantageous to operatives exposed to high dry bulb temperatures. Under ordinary atmospheric conditions a rise of dry bulb temperature is usually accompanied by an increase in the difference between the wet and dry bulb readings, but in humid weaving sheds a nearly constant difference between these readings is maintained with the result that the heat lost by the body through the processes of radiation and convection is considerably reduced, and the additional cooling effect produced by the effects of evaporation is impaired because of the high degree of humidity in the shed. Thus all the physical factors appear to conspire to produce unsatisfactory shed conditions during the summer months.

5. Comparison between cotton weaving sheds and other places.

In order to give a clearer conception of the precise significance of the results described in the previous sections of the report, it is of interest to show how the atmospheric conditions in humid weaving sheds compare with the conditions found elsewhere.

TABLE VIII.—*Summary of observations taken in different places.**

Place of Observations.	Temperature (°F)		Cooling Power.		Air Velocity (ft per min)
	Dry Bulb.	Wet Bulb	Dry Kata.	Wet Kata.	
Out of Doors (bright, pleasant day in May)	68	60	7·5	27·2	79
Brass Foundry (good) .. .	72	60	7·3	24·0	119
Machine Shop (bad) .. .	72	61	4·6	15 0	18
Cartridge Annealing and Cleaning (bad)	80·5	64·5	3·0	17·5	16
Cartridge Annealing and Cleaning (good)	60 0	54·5	9·0	24·0	64
Boot Factories (Summer) :—					
Clicking Rooms	67·0	—	6·2	16·8	33
Closing Rooms	66·0	—	6·5	18·3	33
Press Rooms	65·5	—	6·7	17·0	38
Lasting Rooms	67·0	—	6·3	17 5	35
Finishing Rooms	67·0	—	6·5	18·5	41
Shoe Rooms	66·4	—	6·7	18 0	42
Clicking Rooms	61·2	—	7·5	20 2	36
Closing Rooms .. .	64·0	—	7·0	19·9	38
Boot Factories (Winter) —					
Press Rooms	61·3	—	7·4	20 2	34
Lasting Rooms	62·0	—	7·5	19 8	39
Finishing Rooms	62 3	—	7·7	20·9	46
Shoe Rooms	59·0	—	7·7	19·7	31
Humid Weaving Sheds :—					
Summer	74·6	69·3	4·4	13·6	25
Winter	69·8	65·2	5·4	15·0	27

* "Preliminary Notes on Atmospheric Conditions in Boot and Shoe Factories." (*Industrial Fatigue Research Board, Report No.* 11, *p.* 33).

The cooling power of the air in humid weaving sheds (even during the winter months) compares unfavourably with that observed in the other industries given in the table. This is due to the higher temperature and humidity found in humid sheds and indicates that the operatives in these sheds are exposed to adverse physiological conditions which may impair their general health and physical fitness.

A further comparison between cotton weaving sheds and certain other workrooms is given in Table IX. To enable an accurate comparison to be made between summer and winter readings, only the data relating to the sheds investigated over both periods (i.e., sheds A, B, C, D, E) have been included.

TABLE IX.—*Cooling power of air in cotton weaving sheds, potters' shops,* boot and shoe factories,† and laundries.‡ (Percentage frequencies.)*

Dry Kata Cooling Power.	Cotton Weaving Sheds.		Potters' Shops		Boot Factories.		Laundries.
	Winter	Summer	Winter	Summer	Winter	Summer	Summer.
Below 2 ..	0	0	0	0	0	0	19
2 to 2·9 ..	0	1·5	0	6	0	0	17
3 to 3 9	2·5	33·3	3	23	0	8	**21**
4 to 4·9 ..	36·1	**45 2**	18	**34**	1	10	19
5 to 5·9 ..	**42·4**	19 3	**40**	26	4	19	12
6 to 6·9 ..	17 1	0 7	24	8	28	**28**	7
7 to 7·9 .	1·9	0	12	2	**35**	20	4
8 to 8·9 ..	0	0	3	1	18	9	0·7
9 or more ..	0	0	0	0	14	6	0·3
Total Observations ..	158	135	289	463	377	276	300

* "Two Investigations in Potters' Shops" by H. M. Vernon, M D. (*Industrial Fatigue Research Board, Report No* 18)

† "Preliminary Notes on Atmospheric Conditions in Boot and Shoe Factories," by W D Hambly, B Sc, and T Bedford. (*Ibid, Report No* 11)

‡ "Some Studies in the Laundry Trade," by May Smith, M A. (*Ibid, Report No* 22)

Although the number of observations taken in cotton weaving sheds is rather small, they serve to indicate that the conditions in cotton weaving compare very unfavourably with those in boot and shoe factories, and are slightly worse than those in potters' shops, but that they are much superior to those in laundries.

The average air velocity in weaving sheds is 26 feet per minute, while the corresponding values for potters' shops, boot and shoe factories, and laundries, are approximately 19, 36, and 45 feet per minute. The average temperature in weaving sheds is higher than that of potters' shops and much higher than that of boot and shoe factories, consequently temperature is responsible for the lower cooling power of the air in weaving sheds as compared with potters' shops, but in boot and shoe factories a higher rate

of air movement, in addition to a lower temperature, makes the conditions more satisfactory. The temperature in laundries is higher than in weaving sheds, and although the air movement in laundries is about twice that of weaving sheds, it is unable to raise the cooling power to that observed in the latter industry.

6. Miscellaneous Observations.

A. The Influence of Machinery and Belting and of other Factors on Air Movement.

As has been already stated, a dry kata cooling power of six is considered to be the minimum standard for workers engaged in sedentary occupations. Since the dry kata cooling power is a function of, (*a*) the temperature of the air, and (*b*) the rate of air movement, it can be increased either (*a*) by lowering the temperature of the shed or (*b*) by increasing the rate of air movement. The former method has already received much attention from the industry, but the latter has been comparatively neglected. It seemed desirable, therefore, to pay special attention to the subject of air movement, by investigating some of the factors producing it. In addition, a small-scale experiment designed to increase the air velocity in the vicinity of the loom (see Appendix I, p. 30) has been carried out.

In a weaving shed the air is disturbed by the action of the machinery. An attempt was made to determine the effect of the machinery movements upon atmospheric conditions by taking readings during the dinner hour when the machinery was stopped and comparing them with those recorded when the machinery was in motion. In the absence of other disturbing factors, one would expect to find a decrease in the rate of air movement during the dinner hour, but in several instances this theoretical expectation was not realised because of the admission of outside air due to the frequent opening of the shed doors.

Some additional results were obtained during the working period in head level position between looms which were alternately stopped and in motion. The averages of the observations made in the same position on eight different days are given in Table X.

TABLE X.—*Showing effect of machinery movements on cooling power of air.*

Looms	Observations.	Temperature (°F)				Cooling Power				Air Velocity (ft per min)
		Dry Bulb.	M.V.	Wet Bulb.	M V	Dry Kata	M V.	Wet Kata	M.V.	
Working	8	68·0	1·4	64·6	1 4	6·0	0·3	17·7	0·6	33
Stopped	8	68·2	1·4	64·6	1·4	5·5	0·3	16·7	0·9	22

The results indicate that at the head level of the weaver, the motion of the looms increases the air velocity by 50 per cent., and so brings about an appreciable increase (approximately 9 per cent.) in the cooling power of the air. The rate of cooling of the wet kata is also increased from 16·7 to 17·7, or 6 per cent. These increases were due chiefly to the movement of the sley which moves backwards and forwards a distance of approximately one foot in a horizontal plane at a rate of 100 complete oscillations per minute.

In the shed in which these observations were made the looms had the individual form of electric drive and the belting which usually forms such a conspicuous feature of a weaving shed was absent. In most weaving sheds steam power is used and the power is transmitted from overhead line-shafts to each loom by means of belting. It appeared probable that the movement of the belting would affect the cooling power of the air in its vicinity and an attempt was made to determine the nature and extent of this effect by taking readings in positions at varying distances from the belting. Six observations were made on different days in each position and the averages of the results obtained are given in Table XI.

TABLE XI.—*Showing effect of belting on cooling power of air.*

Distance from Belt.	Temperature (°F.)				Cooling Power				Air Velocity (ft per min.).
	Dry Bulb.	M.V.	Wet Bulb.	M.V.	Dry Kata	M.V.	Wet Kata	M.V.	
3 ins.	66·2	1·7	62·8	1·2	7·0	0·7	20·1	1·6	49
6 ins	66·6	1·6	62·8	0·8	6·9	0·6	19·5	1·1	49
9 ins.	66·6	1·5	63·3	1·1	6·7	0·7	18·8	1·5	44
12 ins	66·9	1·7	63·5	1·4	6·4	0·7	17·6	1·1	37
10 ft	67·1	1·7	63·7	1·5	5·7	0·4	16·3	0·8	23

Thus the cooling power of the air increases as the distance from the belting diminishes, and since the temperature remains almost constant, this increase is due to the increased air velocity.

The effective range of the air disturbances caused by the belting is considerably greater than one foot, since at that distance the air velocity is still 65 per cent. greater than that in a position ten feet from the belting and entirely outside its influence. In a position three inches from the belting the increase in air velocity is about 100 per cent., causing an increase in cooling power of 20 per cent. In this respect a steam-driven shed appears to have a slight advantage over one having the individual electric drive, though this may be easily neutralised by other factors.

Another possible method of improving the atmospheric conditions in humid weaving sheds consists in a system of ventilation in which conditioned air is used. By means of suitable apparatus the temperature and humidity of the incoming air can be controlled and its velocity regulated. An apparatus which is said to *maintain* a dry bulb temperature of 72·5 and a relative humidity of 80 per cent. throughout the summer months is now on the market. This apparatus also controls the velocity of the incoming air, and consequently seems worthy of consideration.

The cooling power of the air in the vicinity of the looms has also been increased by attaching a strip of canvas to the heald roller. The method adopted and the results obtained are fully described in Appendix I (page 30).

B.—Comparison Between Head and Floor Level.

In one of the sheds mentioned in this report (Shed A) observations on the cooling power of the air were made at floor level. A comparison of these with others obtained at head level in the same shed is given in Table XII.

TABLE XII.—*Cooling power of air at head and floor levels.*

Level.	Observations.	Temperature (° F)				Cooling Power.				Air Velocity
		Dry Bulb.	M.V.	Wet Bulb	M.V.	Dry Kata	M.V.	Wet Kata	M.V.	
Head ..	40	70·7	2·5	65·8	2·5	5·4	0·6	14·8	1·2	31
Floor ..	16	69·3	2·1	65·7	1·7	5·9	0·5	15·0	1·1	37

It will be seen that the dry kata cooling power is greater at floor level than at head level. This difference is due both to the increased movement of the air and to the slightly lower temperature at floor level.

These results show that the feet tend to be cooled more rapidly than the head. Normally, the head should be slightly cooler than the feet, and in this respect the heating and humidifying arrangements in humid weaving sheds probably act adversely upon bodily comfort and efficiency. A higher temperature and degree of humidity at floor level would also be more in accordance with the technical requirements of weaving.

C.—The Effect of Moving Air upon Skin Temperature.

A few experiments were made in a closed laboratory in order to illustrate the effects of moving air upon the temperature of the cheek. The subject was seated three feet from a small fan

and had one cheek exposed to the current of air created by the fan. The temperatures of both cheeks were taken simultaneously at intervals of two minutes by means of maximum reading surface temperature thermometers, and the following are typical of the results obtained.

TABLE XIII.—*The effect of air movement upon skin temperature.*

Series 1					Series 2				
Temperature (° C)			Fan	Air Velocity (ft per min)	Temperature (° C)			Fan.	Air Velocity (ft per min).
Room	L Cheek (Exposed)	R Cheek			Room	L Cheek (Exposed)	R Cheek		
20·2	34·3	34 6	Stopped	—	20·4	34 3	34 5	Stopped	—
,,	33·4	34·4	Running	39	,,	32·3	34 3	Running	70
,,	32 8	34·6	,,	,,	,,	31·8	34 3	,,	,,
,,	33 0	34 5	,,	,,	,,	31 8	34 4	,,	,,
,,	32 8	34 6	,,	,,	,,	32·0	34·0	,,	,,
,,	32·8	34 5	,,	,,	,,	31 7	34·3	,,	,,
,,	32·3	34 6	,,	,,	,,	32·1	34·2	,,	,,
,,	32·4	34 5	,,	,,	,,	31·3	34 2	,,	,,
,,	32·3	34·3	,,	,,	,,	31·5	34·2	,,	,,

The increased movement of the air causes an appreciable decrease in the temperature of the exposed cheek, which is maintained throughout the duration of the experiment (about 20 minutes), whereas the temperature of the protected cheek remains nearly constant. A velocity of approximately 70 ft. per minute produces a slightly greater decrease than one of 39 ft. per minute, but in both cases the effect of the increased velocity is very quickly seen.

These results are merely suggestive, and a more extensive and varied series is necessary in order to show the effect of prolonged exposure to air movement and the probable reaction which takes place when the fan is stopped.

The maintained difference in temperature between the two cheeks indicates that within the limited duration of the experiment the increased cooling effect is restricted to the area of the skin exposed to the current of air, and that this difference in local temperature is chiefly responsible for the perception of air movement.

Observations on the body temperature of weavers in humid weaving sheds by Legge,* and Pembrey and Collis,† show that the effect of a warm moist atmosphere is to " diminish the difference between the internal temperature of the body and that of the

* Second Report of the Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds, 1911, p 15.

† *Ibid.* p 24

peripheral parts." In other words, the surface temperature of the body is increased until it approximates to the internal temperature. Such a condition maintained over a long period is physiologically harmful, and consequently an arrangement which will counteract the rising tendency of the surface temperature of the body will probably have a beneficial effect. The above results show that an increase in the rate of air movement will secure this effect, and the practical application of this principle to humid weaving sheds deserves consideration.

D.—Notes on Clothing.*

The question of the most suitable kind of clothing for operatives in weaving sheds does not appear to have received the attention it deserves. Since the maintenance of a state of equilibrium between the rates at which the body produces and loses heat is of vital importance, it becomes necessary to consider all the factors which tend to modify this state. Clothing is undoubtedly one of the most important of these, and the miscellaneous assortment worn by operatives in weaving sheds suggests that some clothes are much more suitable than others in their effect upon bodily comfort and efficiency.

Hill has shown that a naked man loses heat twice as rapidly as one clothed, but in the latter case the rate of heat loss depends upon the nature and amount of clothing worn. Thus, if the radiant heat emitted from the naked skin in a room at 59° F. is taken as 100, it is reduced by :—

a wool vest to 73,
a wool vest and linen shirt to 60,
a wool vest, linen shirt and waistcoat to 46.†

Further, the dry kata cooling power when the bulb of the kata was covered with the following materials was found to be—‡

	Knitted Wool.	Silk.	Open Cotton Mesh	Close Cotton Mesh.	Naked.	Temp. (°F.)
In room	4·8	6·0	6·1	5·7	6·1	60–63
In wind§	7·0	11·1	12·0	11·1	10·8	64–65

Thus the rate of heat loss is appreciably affected by the material used, and the superiority of a fabric with open mesh is clearly shown. The properties of a garment have been found to depend almost wholly upon the manner of its weaving, and not upon the kind of material. Experiments by Flack and Hill|| have led them

* This section of the report is an attempt to apply some of the facts given in "The Science of Ventilation and Open-Air Treatment," Parts I & II, by Leonard Hill, M.D., F R.S. (*Medical Research Council, Special Report Series, Nos* 32 *and* 52). The footnotes refer to the pages in these books.

† Part II, p. 226.

‡ Part II, p. 239.

§ Velocity 3 ft per second approximately.

|| Part II, p. 244.

to state that "It made little difference whether the shirt was cellular cotton or flannel or flannelette, the protection from cooling depending on the restriction of ventilation, not on the nature of the material."

In weaving sheds, especially during the summer months, the temperature frequently exceeds 80° F. The human body strives to maintain itself at a temperature of 98·4° F. As the shed temperature rises, heat lost by radiation and convection becomes proportionately reduced, and in the case of very high temperatures, almost all the heat lost is by the process of evaporation. To promote evaporation, the rate of movement of the air in contact with the body must be increased, but in weaving sheds air movement is comparatively slight. As a result the air in the meshes of the clothing and between the clothing and the surface of the body, tends to approximate to body temperature and becomes saturated with moisture. In this respect it resembles the atmosphere of a moist, tropical climate, and retards very considerably the rate of heat loss from the body. "Every hindrance to heat loss either reduces bodily exertion or causes the exertion to be done under a feeling of oppression and a burden of weariness,"* hence it seems highly probable that the bodily comfort and efficiency of the weavers is impaired, especially during the summer months, by the unsuitability of the clothing worn in many cases. "There are hot, moist mines where the day's working power of the white is reduced by the strain on his heat losing mechanism to no more than the equivalent of two hours' labour performed out of doors."† Although the nature of the work in a weaving shed is very different from that performed in a mine, the effect upon the operatives will be similar in kind but different in degree.

In the case of male operatives, a certain amount of relief is obtained by exposing the arms and chest to the air, but in the case of the women this is not done to the same extent. Inadequate heat loss involves the use of the sweating mechanism, the prolonged operation of which throws a definite strain on the circulation, *i.e.*, on the heart. For use in weaving sheds, light clothing, permeable to air, which promotes evaporation, is the most suitable, such as loose cotton garments and material having a cellular structure. Before passing into the outside air, thicker and warmer clothing should be added. This additional garment should be kept in a suitable cloakroom and not in the weaving shed as is frequently the case. When kept in the shed it becomes humidified by the steam used for humidification purposes, and although at the temperature of the shed it may appear to be fairly dry, when exposed to the cooler outside air the water vapour absorbed by the material condenses and the garment becomes damp. The evaporation of this moisture lowers the temperature

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* Part I, p 56.

† Part I, p 59.

of the parts in contact with it, and the cooling effect thus produced causes chilling which is prevented by an outer dry garment. In the matter of keeping warm wool has an advantage over other textiles while wet, since it does not cling to the body and entangles air under its elastic fibres. The clothing question is an important part of the field of industrial hygiene, and the operatives should receive advice and instruction in this connection. In the near future it will probably form an important feature in the welfare scheme, but whatever organisation eventually becomes responsible for its development, the importance of this aspect of industrial life cannot be denied.

The rate of heat production varies in different individuals, and in the same individual under different conditions. Weavers accustomed to working in hot moist atmospheres have their rate of heat production reduced, and when outside the shed feel the cold more than the average person. The paleness of the skin usually associated with weavers is largely due to the same cause. Under fairly uniform atmospheric conditions, the body tends to become adapted to its physical environment, and although the exposed parts of the body may be at a lower temperature than those which are clothed, the difference is not perceived by the individual. The changes experienced in passing from the street to the weaving shed illustrate this point. Prolonged exposure to the shed conditions causes a readaptation in body temperature, and if the shed is not uncomfortably hot, the body temperature again appears to be uniform and the differences perceived on entering disappear. It seems probable that the weavers become better adapted to the higher temperature, humidity, and uniformity of air movement which usually prevail in humid weaving sheds, and conditions which cause discomfort to the new arrival are borne with equanimity by the experienced weaver. Adaptation to abnormal atmospheric conditions does not necessarily imply the existence of a normal state of health, and it is hoped that a study of sickness records will yield conclusive evidence in this connection.

"Monotony of the atmospheric conditions and the reduction of the body metabolism by diminished rate of cooling, with the consequent loss of nervous tone and disordered digestion, are, we believe, the chief causes of the ill-effects of confined sedentary occupations."*

Hill states that in order to work comfortably at 77° F. with a relative humidity of 47 per cent., a man requires a wind of 0·5 to 1·0 metres per second.† In humid weaving sheds in which the humidity is much higher, the air velocity is generally about

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* "The Measurement of the Rate of Heat Loss at Body Temperature by Convection, Radiation and Evaporation," by L Hill, F.R.S., C. W. Griffith and Martin Flack *Phil. Trans. of the Royal Society*, B. Vol. 207, 1916, p. 184.

† Part I, p. 137.

one-third of this value. The body is also stimulated by temperature changes, but in weaving sheds the variations in temperature are slow and gradual. As a result a state of equilibrium is established between body temperature and the atmospheric conditions in the shed, and the stimulating effect of variations in temperature is entirely lost. "The adequate movement of the air makes a high wet-bulb temperature much less oppressive, and thus by ensuring sufficient movement a humidity can be secured for trade purposes which otherwise would be uncomfortable and deleterious to work-people."* The experiments with the strips of canvas attached to the heald rollers (*see* p. 30), produced variations in the surface temperature of the body by modifying the rate of air movement in its vicinity, and the principle involved is worthy of further development and application.

7. Summary.

1. For workers engaged in sedentary occupations, a dry kata rate of cooling of 6 and a wet kata rate of cooling of 18 are considered to be the desirable minima. In humid weaving sheds these standards are seldom reached. (pp. 5, 8, 14, 15, 17, 19.)

2. During the winter months, when the shed temperatures are comparatively low, the average dry and wet kata readings are approximately 5 and 15 respectively. These conditions appear to be sufficient to prevent visible sweating in the case of the operatives, yet the air is fairly stagnant and fails to have the effect usually associated with pleasant conditions in the open air. (pp. 5, 6)

3. During the summer months the cooling power of the air in the sheds is considerably reduced, and is much below the standards given above. The operatives are exposed to atmospheric conditions which are physiologically unsatisfactory and devices which will protect them from the effects of the prevailing high temperatures and humidities should be adopted whenever possible. (p. 15 to 20.)

4. Whenever the cooling power of the air is insufficient to prevent visible sweating on the part of the operatives, the low evaporative power, produced by the admission of steam, is unable to give the relief needed by operatives exposed to high dry bulb temperatures. Under more ordinary conditions an increase in the dry bulb temperature is usually accompanied by an increase in the difference between wet and dry bulb readings, but in humid weaving sheds a constant difference between these readings is maintained, with the result that the heat lost by the body through the processes of radiation and convection is considerably reduced, and the additional cooling effect produced by evaporation is impaired because of the high degree of humidity in the shed. (pp. 16, 20).

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* *Phil. Trans.*, op. cit, p. 213.

5. In general, the results obtained in the different sheds show that the cooling power of the air becomes distinctly unsatisfactory when the shed temperature exceeds 70° F. For higher temperatures, a satisfactory cooling power can only be obtained by increasing the rate of air movement. (pp. 5, 8, 15, 17, 30.)

6. Considerable differences in the cooling power of the air exist in the different sheds. Since all the sheds are exposed to fairly similar outside atmospheric conditions, the shed temperatures and humidities, and consequently the cooling power of the air in the sheds, are, within limits, under the control of the management, and the differences observed are largely due to the different quantities of steam which are forced into the sheds for humidification purposes. (pp. 5, 15.)

7. Hourly observations show that the cooling power of the air in the sheds decreases during the morning spell, rapidly at first but more slowly afterwards. During the dinner hour an increase is noticeable which is followed by a gradual fall during the afternoon spell. Thus atmospheric conditions which may be favourable at the beginning of the working day become more unfavourable as the day proceeds. (pp. 8, 17.)

8. Machinery movements cause an appreciable increase in the cooling power of the air in the vicinity of the operatives. The increase, even though imperceptible, yet cannot fail to have a beneficial physiological effect. (pp. 22, 23.)

9. The cooling power of the air in humid weaving sheds compares unfavourably with the rate of cooling observed in the other industries mentioned in this report. (pp. 20, 21.)

10. The air movement in the vicinity of the weaver can be increased by attaching a three-inch strip of canvas to the heald roller on the loom. This device is inexpensive and easily attached, and is able to maintain a cooling power above the necessary standards for high shed temperatures. Owing however to the fact that the weaver when examining the warp sometimes places her head near the heald roller, the device described would probably have to be modified in practice. (pp. 30, *et seq.*)

APPENDIX I

An Experiment in Increasing the Cooling Power of Air in a Humid Weaving Shed.

In this experiment an attempt was made to apply the principles already described to the conditions at present existing in humid weaving sheds. For this purpose the rate of air movement, and consequently the cooling power of the air in the vicinity of the weaver was increased by attaching strips of material of various widths to the heald roller, as shown in Figs. A and B.

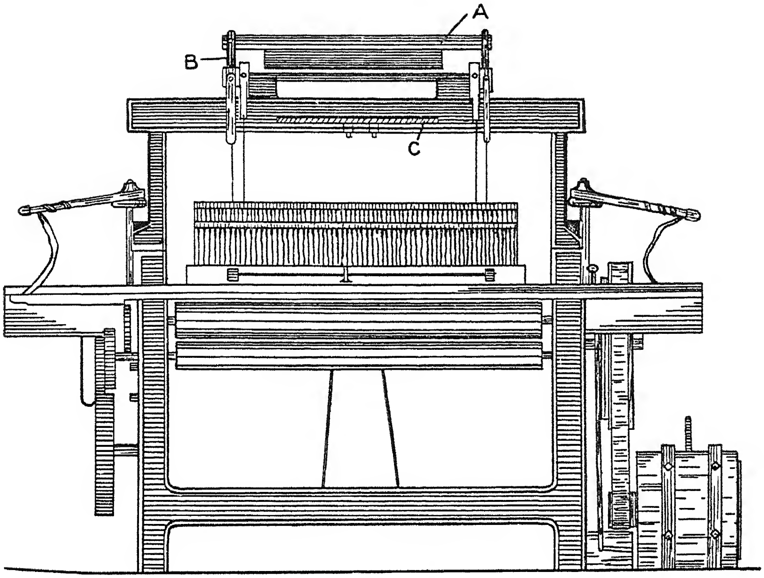

FIG A

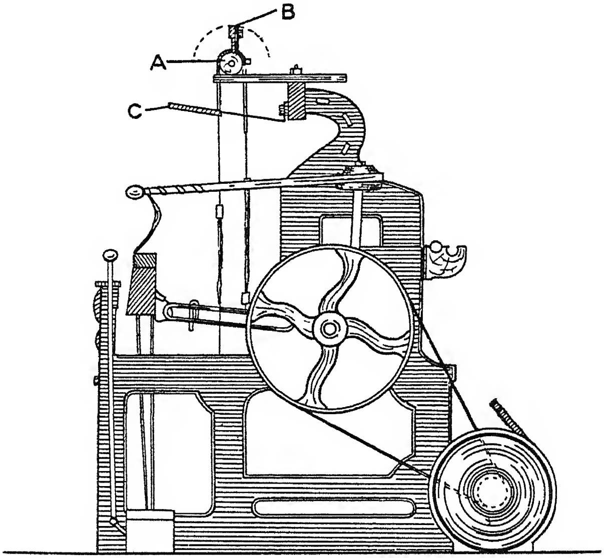

FIG. B.

The boards (B) used were $2\frac{1}{2}$ feet long and when the loom was in motion oscillated through an angle of 180° at a rate of 100 complete oscillations per minute. A fixed board (C) deflected the air towards the weaver and at the same time protected the warp. Such an arrangement was attached to opposite looms and observations on the cooling power of the air were made in different positions between the looms.

The results, based on eight observations in each position, are given in Table A :—

TABLE A.—*Showing effect on cooling power of air of device for increasing air movement* (*Boards*).

Conditions.	Temperature (°F)		Cooling Power		Air Velocity (ft per min).
	Dry Bulb	Wet Bulb	Dry Kata	Wet Kata	
Between Looms :					
Looms stopped .. .	68·2	64·6	5 5	16·7	23
Looms working	68·0	64·6	6·0	17·7	33
3-in. Board on Looms ..	68·0	64·6	6·9	20·2	58
Three inches from Board C :					
3-in. Board on Looms ..	68·2	64·6	9·3	25·9	164

It will be seen that although the temperature remains constant, a large increase in the rate of cooling takes place, due to the greatly increased air velocity. Even at a point midway between the looms where the effect of the boards on the weaver is at a minimum, the air velocity is nearly doubled and the dry kata rate of cooling is raised from 6·0 to 6·9 (15 per cent.) by means of the three-inch board.

Frequently the weaver is much nearer the moving strips, especially when she is stooping over the warp in order to repair breakages. In such cases the proximity of the source of air movement causes an increased cooling effect, as will be seen from a comparison of the above results with those obtained at a distance of three inches from the fixed board C. The wet kata cooling rate is also favourably affected by the increased air movement, though the rate of increase is not quite as great as in the case of the dry kata.

During the tests, the air movement produced by the three-inch board was distinctly pleasant and much to be preferred to the comparatively warm, stagnant feeling which was noticeable when the looms stopped.

Although a three-inch strip will not raise the dry kata cooling rate to 6 during the very high temperatures which prevail in weaving sheds during the summer months, it will materially increase the cooling power, and therefore add to the comfort of the operatives.

Since there is a possibility of the three-inch board striking the weaver, experiments were made with a protective device attached to the loom (*see* Figs. C and D), consisting of a semi-circular tin shield (D) which entirely covered the moving board with the exception of an opening two inches wide at the front end of the shield. The air was driven through the opening by the moving board and deflected towards the weaver by a horizontal board (C) placed under the shield and projecting about two inches in front of it.

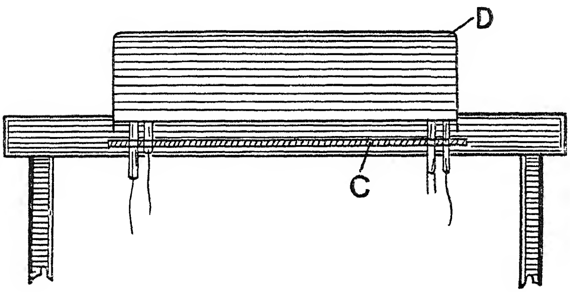

FIG C

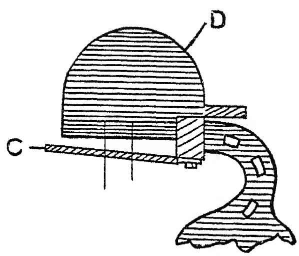

FIG D.

The results obtained in this experiment are given in Table B

TABLE B.—*Showing effect on cooling power of air of device for increasing air movement.* (*Board and shield*).

Conditions	Temperature (°F)		Cooling Power.		Air Velocity (ft. per min.).
	Dry Bulb	Wet Bulb.	Dry Kata	Wet Kata	
Looms stopped	71·8	68·5	4·7	14·4	20
Looms working . ..	71·8	68·5	5·3	16·1	34
3-in. Board on Looms.. ..	72·2	68·5	5·6	19·1	47
3-in. Board 3 in. from Looms	72·3	68·7	7·4	22·2	123

The general effect of these conditions is similar to that observed in the previous table, but the rate of cooling does not increase at the same rate as in the last experiment. The protective device appears to reduce the rate of the air current deflected towards the weaver, and a noticeable increase in the cooling power of the air was observed when the cover was removed. The metal shield also looked somewhat unwieldy, and it was thought advisable to dispense with this arrangement.

An experiment was then tried with a stiff canvas about three inches wide attached at the ends to two metal supports on the heald roller; the horizontal board being still retained to deflect the air towards the weaver. The following are the results obtained with this arrangement:—

TABLE C.—*Showing effect on cooling power of air of device for increasing air movement.* (*Canvas strips*).

Conditions	Temperature (°F.)		Cooling Power		Air Velocity (ft per min)
	Dry Bulb	Wet Bulb	Dry Kata	Wet Kata.	
Looms stopped.. . ..	72 7	68·7	4 6	13 4	21
3-in canvas on: Looms working	73 3	68 2	9 0	25 9	243
3-in canvas 3 in from Loom..	72·5	68·4	10 7	30 3	346
Cover on Looms working ..	73·0	68 7	5 4	16 0	46
Cover on: 3 in from opening	73·0	69·8	8 2	25 2	193

The above results indicate the increased cooling effect produced by the exposed strip of canvas. The rate of cooling of both the wet and dry kata is raised well above the standards recommended for persons engaged in sedentary occupations, and even with a shed temperature of 80° F. the rate of cooling of the dry kata would still be about 6·4 in a position midway between the looms. The effect of enclosing the canvas in the metal shield is clearly seen in the results and confirms the advisability of dispensing with the shield arrangement. The exposed strip of canvas seems to be the best arrangement yet tried and has the additional advantage of being simple, cheap, and easily attached to the looms. Owing, however, to the fact that the weaver when examining the warp sometimes places his head near the heald roller, the device described would probably have to be modified in practice.

APPENDIX II

Instructions for using the Kata-Thermometer.

The observations dealt with in this report were taken by means of the kata-thermometer, an instrument designed to measure it own rate of cooling at a temperature approximately that of the human body. The kata-thermometer has an alcohol reservoir in the form of a cylindrical bulb about 1½ in. long, and ¾ in. in diameter. The stem, which is graduated in tenths of a degree from 95° to 100° Fahrenheit, has at the top a small bulb which acts as a safety overflow when the thermometer is heated.

Readings are taken with the kata used both as a dry bulb and as a wet bulb thermometer. Dry readings are taken by immersing the large bulb of the kata-thermometer in water having a temperature of about 180° F, until an unbroken column of the spirit has risen half way up the safety bulb The alcohol rises slowly when first the reservoir is immersed in hot water, but this slow movement is followed by a sudden rise, and care is necessary in order to avoid fracture of the safety bulb The instrument is cooled for a minute so as to enable the glass to get into equilibrium. Then the thermometer is re-heated, and after bulb and stem have been wiped quite dry, the kata is placed in the desired position, preferably suspended from a stand The time in seconds which is occupied by the thermometric liquid in falling from 100° to 95° F, *i.e*, through a range of temperature approximating to that of the human body, is noted by means of a stop watch From three to five readings are, as a rule, sufficient for calculating an average rate of fall, from which the rate of cooling is estimated, though a larger number of observations of rates of fall is advisable when the kata-thermometer is used in positions where puffs of wind alternate with calm intervals The same procedure is followed when "wet readings" are taken, excepting that a tightly fitting cover of Lisle silk knitted glove is stretched over the reservoir of the kata-thermometer Excess of moisture is jerked off before the instrument is suspended for observation

The average time of fall thus obtained gives an indication of the rapidity with which heat is lost by the particular instrument used, but owing to such variables as the thickness of the glass, and slight variations in surface area, two different instruments would give different times of fall, even under identical circumstances and methods of experiment Readings are standardised, so that the rate of heat loss can be expressed in heat units per unit area per second, by using a "kata factor" ascertained for each instrument before it leaves the maker; this factor, which is stamped on the stem near to the top bulb, is found by determining the water equivalent of the thermometer, and actually represents the amount of heat in milli-calories per square centimetre of surface required to raise the thermometer from 95° F. to 100° F. Hence by dividing the factor by the number of seconds taken by the fluid in falling through this range of temperature, the rate of heat loss in milli-calories per square centimetre per second is obtained

> *Example*—Suppose that the average of five readings of the time taken by the column to fall from 100° F to 95° F. is 91 seconds, and that the kata factor marked on the stem of the instrument is 476. Then 476 is divided by 91, giving 5·2, which is taken to represent the cooling power of the air at that time and place.

It should be noted that when the temperature of the air exceeds 95°, the cooling power cannot be estimated, and is in fact zero or even a negative quantity. Even at somewhat lower temperatures the estimation is difficult, owing to the long time required by the column to fall In such instances, it is generally sufficient to note that the cooling power is less than a specified value (such as 2).

For the calculation of "air velocity," the *temperature* as well as the cooling power of the air is required. It is, in fact, generally desirable, whenever kata readings are made, to obtain simultaneous readings of the temperature (if possible both dry and wet bulb) both inside the building in the same part where the kata is used, and outside the building in the open air.

To obtain the air velocity (in feet per minute) the cooling power of the air (determined as described above) is divided by the difference between 97·7 and the observed temperature in degrees Fahrenheit. The resulting quotient is looked for in the table given below in one of the columns headed $\frac{H}{\theta}$, and the figure opposite in the column marked V is the value required. If the quotient is intermediate between two values of $\frac{H}{\theta}$, the value of V can be easily estimated by interpolation.

Example—Suppose that in the example already given, the observed temperature of the air was 75·5° F The cooling power, 5·2, is divided by 97·7—75·5, *i e*, 22·2, giving 0·234 This figure is intermediate between 0·23 and 0·235 in the first column of the table, and it can be easily seen that the corresponding value for the air velocity is 60 feet per minute.

The following table shows the values of V for different values of $\frac{H}{\theta}$. Intermediate values can be quickly found by interpolation

Air velocities for varying values of $\frac{H}{\theta}$ *(British Units).*

$\frac{H}{\theta}$	V.	$\frac{H}{\theta}$.	V.	$\frac{H}{\theta}$	V.
·155	8	·27	100	·39	280
·16	10	·275	106	·395	289
·165	12	·28	113	·40	298
·17	14	·285	120	·405	307
·175	16	·29	127	·41	316
·18	19	·295	134	·415	325
·185	22	·30	141	·42	335
·19	25	·305	148	425	345
·195	28	·31	156	·43	355
·20	32	·315	164	·435	365
·205	35	·32	172	·44	375
		·325	181		
·21	39	·33	190	·445	386
·215	43	·335	198	·45	396
·22	47			·455	406
·225	52	·345	207	·46	417
·23	56	·35	214	·465	428
·235	61	·355	222	·47	439
·24	66	·36	230	·475	450
·245	71	·365	238	·48	461
·25	76	·37	246	·485	473
·255	82	·375	254	·49	484
·26	88	·38	262	·495	496
·265	94	·385	271	·50	508

Note—The above table is based on the following formulae, giving the relation between dry kata cooling power, temperature and air velocity.

For air velocities greater than 8 but less than 200 ft. per minute :—

$$\frac{H}{\theta} = (0\cdot11 + 0\cdot016\sqrt{V})$$

For air velocities greater than 200 ft per minute :—

$$\frac{H}{\theta} = (0\cdot072 + 0\cdot019\sqrt{V}).$$

where H = dry kata cooling power (found by dividing the "kata factor" by the time in seconds taken by the fluid in falling from 100° to 95° F.).

θ = (97·7—t) where t = air temperature in degrees Fahr.

V = air velocity in feet per minute.

Similar formulae hold in regard to wet kata cooling power and air velocity, but these lend themselves much less easily to calculation.

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HILL, L, VERNON, H M., and HARGOOD-ASH, D (1922): The Kata-Thermometer as a Measure of Ventilation.—*Proc. Roy. Soc.*, B. **93**, 198.

MUSCIO, B. (1920): Fluctuations in Mental Efficiency.—*Brit. Journ. Psych*, **10**, Part 4.

MUSCIO, B. (1921): Is a Fatigue Test Possible?—*Ibid.*, **12**, Part 1.

MUSCIO, B. (1921): Feeling Tone in Industry.—*Ibid.*, **12**, Part 2.

RUSHER, E. A. (1922): The Statistics of Industrial Morbidity in Great Britain.—*Journ. Roy. Stat. Soc.*, **85**, 1.

STURT, M. (1921): A Comparison of Speed with Accuracy in the Learning Process.—*Brit. Journ. Psych.*, **12**, Part 3

VERNON, H. M. (1921): The Influence of Fatigue on Health and Longevity.—*Journ. Ind. Hyg.*, **3**, 3.

VERNON, H. M. (1922): The Influence of Rest Pauses and Changes of Posture on the Capacity for Muscular Work—*Journ. Physiol.*, **56**, 47.

VERNON, H. M. (1922): Atmospheric Conditions in Industry.—*Journ. Ind. Hyg.*, **4**, 8.

WILSON, D. R. (1921): Some Effects of Environment on Fatigue and Efficiency.—*Journ. Roy. San. Inst.*, **42**, 8.

WILSON, D. R. (1921): The Work of the Industrial Fatigue Research Board and its Applications to Industry—*Journ. Roy. Soc. Arts*, **70**, 3660.

WYATT, S., and WESTON, H. C. (1920): A Fatigue Test under Industrial Conditions—*Brit. Journ. Psych.*, **10**, Part 4.

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PREFACE.

The laundry trade, with which the present report is concerned, occupies a peculiar position in the industrial world. The large majority of industries are productive, in the sense that raw material is converted into finished articles designed to meet the various requirements of man. In laundry work on the other hand the object is not to produce but to renovate, and with the extension of the trade a function which up to comparatively recent years was carried out at the homes of the people, has been gradually transferred to the factory.

This semi-domestic feature of laundry work has resulted in direct dealings with individual customers to a degree unknown in most other industries, and the lack of any intermediary distributing agent involves both a certain lack of elasticity in coping with supply and output and also the necessity of paying special attention to the requirements of individual customers. These peculiarities in turn render the trade specially sensitive to external influences, both economic and seasonal, and make it difficult to adhere to any uniform conditions of work.

This characteristic of laundry work has always been recognised as inevitable, and in the Factory and Workshop Acts, regulating industrial hours of labour, special and substantial latitude has been conceded, as regards both the actual arrangement of hours and the authority to alter them

Laundries accordingly constitute one of the few large trades in the country in which hours of work are not standardised or even regular, and the present investigation was originally started by the Board in the expectation that this very variety in working conditions would render the industry a fruitful field for the study of the factors determining human fatigue and efficiency.

Unfortunately, another feature equally characteristic of the trade (namely, the lack of constancy in the work done) has prevented the complete fulfilment of the Board's original intention. Up to the present, one of the most general methods of exploring the relation between conditions of work and the human factor in industry has been the measurement of output, but in order to apply this method, the units of output must be either uniform, or, at least, convertible into some common unit. The very large variety of articles dealt with in laundries, and the absence of long-continued work on any article of standard type, have made this part of the investigation especially difficult, and the data used in the present report represent only a small fraction of those that have been collected and have been subsequently discarded as not sufficiently reliable.

The conditions governing laundry work in this country are, in fact, to a large extent individual, and for this reason do not readily lend themselves to exploration by numerical methods, although their investigation may be of great interest in relation to

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the social life of the community. The Board therefore feel it incumbent on them to point out that the present report should be accepted rather as a sociological study than as the embodiment of conclusions on the problems investigated. No definite pronouncement for instance can yet be made as to the effects on the workers of the ten-hour day as compared with the nine-hour day.

Nevertheless, so far as it extends, this investigation indicates the great importance of physiological well-being in maintaining a high standard of health and efficiency, and further research might even prove that the health of the worker is more dependent on good general conditions than on the actual number of hours worked. The Board accordingly hope, now that the initial difficulties of the task have been to some extent explored, that the industry itself may feel disposed to co-operate with the Board in continuing the work, more especially since the report discloses several features in which the working conditions appear to be capable of improvement.

The thanks of the Board are due to the following special Committee, formed to direct and supervise the investigation from its inception :—

Professor Winifred Cullis, D.Sc., Professor of Physiology, University of London (*Chairman*).
Mr. R. R. Bannatyne, Member of the Board.
Mrs. Agnes North } Nominated by the Trade Board for
Mr. J. J. Stark } the Laundry Industry.
Miss Hilda Martindale, O.B.E., H.M. Superintending Inspector of Factories.
Miss Mona Wilson, Member of the Board.

September, 1922.

SOME STUDIES IN THE LAUNDRY TRADE.

By May Smith, M.A. (*Investigator to the Board*)

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I.—INTRODUCTION.

Only one generalisation seems to be warranted with regard to the laundry trade as a whole, namely that if a factory calls itself a laundry, then its main occupation is washing soiled linen and clothes. Nothing else can be taken for granted. The building may vary from a modern specially designed laundry with the latest machinery, ventilation appliances, rest and mess-rooms, to a converted house, shop, or stable, where all reconstruction has to be modified by the exigencies of the original building and where there is little or no room for expansion or modern requirements; between these two extremes there is every grade of adequate or inadequate building. Proprietors and managers, like the buildings, represent practically every social class and type of education and ability, and while we cannot say quite as much with regard to the workers, still in many laundries there exist side by side relics of the old washerwoman of a previous generation with the latest product of high class factory girl Turning to plant, the same diversity prevails, on the one hand is the firm anxiously distrustful of the effects of machinery on clothes and wishful to do as much of every process by hand as is compatible with its conditions, while on the other hand is the firm that eagerly tries every new appliance and scraps any machine that can be superseded by a better.

As human nature is not always logical, it is not uncommon to find that one department of a firm has the latest machinery, while in another department archaic types still persist, nor is this survival always dictated by financial considerations It will not, therefore, be a matter of wonder to find the widest diversity in standard of work done and methods of obtaining it, and rarely is this standard a fixed one, even in the same firm or department. It seems fairly true to say that in laundries everything that can vary does vary. It is essentially an individualistic trade, governed for the most part by methods characteristic of a previous generation; the owner usually works in or is intimately connected with the laundry and knows his work people well; in fact, taking the trade as a whole there is a very good relationship between the proprietor and worker, and since a single laundry employs relatively few workers a much more personal note is able to find expression than is possible in the large undertakings so characteristic of the present time. A laundry may employ ten people and a few employ about four hundred, and there is every gradation between these two extremes

Again, while laundry work is more or less specialised, yet some workers can and do assist in departments other than their special one, particularly in the smaller laundries. This makes investigation peculiarly difficult. During the past two years too the laundry trade, like many others, has been suffering from industrial crises. In one sense it is a parasitic trade and reflects with astonishing accuracy the industrial state of the neighbourhood. To have one's

washing done at a laundry is to many people of the nature of a luxury, and hence it is one of the first economies to be practised when necessity so demands ; again, a strike or lock-out in the neighbourhood will markedly reduce the number of workmen's overalls, aprons, etc., sent to the laundry; and even the fine weather affects some laundries, for where there are gardens to the houses, clothes can be dried in the garden and so there is less work at such times for the laundry. A launderer's customers are his competitors.

From the point of view of the work too, there is very considerable diversity. A shirt has to be considered not as being of a fixed standard of difficulty at all times, but as being at any stage from the assumed perfection just out of the maker's hands to a condition of the lowest decrepitude, and obviously the time taken to iron or press out at the latter stage is very much longer than in the first. A sheet or collar also may present any number of peculiarities. To the launderer this variation is part of the day's work, and on the average works out very much the same week by week, but from the point of view of scientific investigation such variations afford at each stage a disconcerting array of problems.* In all the records used in this report particular care was taken to select only those articles that conformed to the same standard.

The present investigation was undertaken on behalf of the Industrial Fatigue Research Board. Up to the year 1914 very little scientific research had been conducted into such problems as the length of the working day, the best division of the hours of the working day, etc. The war forced the investigation of these and allied problems upon the responsible authorities, and the work begun during the war is being continued during peace in the hope that definite scientific knowledge may eventually replace the vague empiricism of the past. All such investigations, however, notwithstanding that substantial progress has been made, remain in the pioneer stage and definite technique has still to be discovered. The more industries are studied, the more knowledge will be available for the assistance of each particular industry.

A laundry usually consists of the following departments :—

I. *The Wash-house*, where the actual washing and starching of the clothes is done. The machines used for washing purposes are most frequently managed by men, but special articles which are done by hand are washed by women. In the wash-house there are also the machines used for extracting the water from the washed articles ; although in some laundries women are in charge of " hydros " yet the tendency is for men to be employed for this

* This point was well brought out in some calender output records kept for 42 weeks The only significant variation was a fall off owing to seasonal shortage of work during the holiday season There were actually many other variations but they were less marked

An analysis of the amounts earned by piece-rate workers for a year merely showed that they earned more in some months because there was more work to be done.

work. Wash-house work involves heavy muscular effort and the general opinion seems to be that with certain exceptions, it is more suitable for men than for women.

II. *The Calender Room.*—Here "flat" work, *i.e.*, sheets, table linen, etc., is passed over steam-heated rollers, by which process it is dried and ironed. This work is always done by women and is fairly heavy.

III. *The Collar Departments.*—Here collars are steamed, polished, moulded and curled, special machines being used for each process. The work is always done by women and does not involve any heavy muscular work; in fact it is, from the muscular point of view, the lightest work in a laundry.

IV. *The Ironing Department*—Here articles which are not flat are either entirely ironed by hand, or finished off by hand, such parts as can be so treated, such as the soft parts of shirts, having been done either on a press or on a "body" ironing machine. This work is entirely done by women and is fairly heavy.

V. *The Packing and Sorting Department*—Here goods entering the laundry are sorted, checked and marked, and finally, after passing through the laundry, are re-assembled to be sent home to the customer. This is on the whole the most responsible department, the work involving a constant attention to detail on the part of each worker as well as speed. The successful sorter and packer must be rapid in movement, mentally alert, have good powers of attention. Much of the work passing through her hands in the sorting room will not involve any special problem, but she must be ever ready to detect peculiarities which must be dealt with subsequently. Muscularly, the work is not particularly heavy, as the goods handled in both packing and sorting are dry, nor are the workers' movements cramped; mentally, this work, in most laundries doing general work, is exacting.

II.—VARIATIONS IN PERFORMANCE.

The investigation has not concerned itself with those laundries which are quite obviously working under bad conditions, but rather with the problem of whether the laundry trade as such is detrimental to the health and fitness of the workers. Many laundries are in buildings which, having been erected for other purposes, are naturally difficult to ventilate and light in accordance with modern requirements. It is to be hoped that these conditions will be remedied, but no investigation into fatigue effects was needed to say that these are bad. Assuming reasonably good conditions, we have tried to analyse out some of the human factors which affect the output curve. An absolute comparison between one factory and another cannot be made, owing to the great diversity existing in the conduct of the different factories; but there is a possibility of making a relative comparison, and it is fair to compare a factory working under one set of conditions with the same factory working under another.

The first problem to be considered is: Does the length of the working day make any measurable difference?

One obvious method of exploring this problem is to trace the output of a given worker or group of workers for every hour of the working day, and to compare the results for days of different duration. When, however, we turn to the various departments of a laundry, we find that the problem of measuring the actual output is very difficult, for the following reasons:—

(1) The actual type of any article done in any given machine does not remain constant for every hour, *e.g.*, a calender is not only used for sheets and table linen, but for towels, handkerchiefs, pillow cases, and even in some cases shirts. It is quite impossible to compare the amount of work done at the end of the day with that at the beginning if quite different articles are being dealt with, nor was it found practicable, owing to variation in the quality of the work for the purpose, to translate one kind of article into terms of another.

(2) Where the same work is being done all day on one machine, the pressure of work is, as a rule, not equal; sometimes a batch of work has to be done with the utmost celerity compatible with the accepted standard, whereas at other times there is no necessary rush.

(3) The same standard cannot be maintained throughout, owing to the individual requirements of individual customers.

Since continuous measurement of output was found to be impracticable, some other measure was needed which might reasonably be assumed to represent the capacity of the worker at any particular time; for this purpose it was decided, as a general principle, to concentrate on that part of any process which was entirely under the worker's own control, taking samples as often during the day as possible, on the assumption that the results so obtained would be indicative of the effects produced by the work carried on during the intervening periods.

1.—*Calender Work.**

In order to measure calender work, the interval elapsing between the workers taking their hands off one article and placing the next was observed. One or two launderers have assured me that in their own works no such interval exists, because the beginning of one article is made to overlap the end of another; although this is an optimistic statement, if they really think that it occurs all day, yet, granted that such is the case, even if there is no space interval, there is a time interval, for the worker must cease to touch the end of one and take up the next, and no amount of overlapping or superior preparation will do away with it.

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* A calender requires for each large article, such as a sheet or table cloth, two workers; so each record is to be understood as applying to the two workers

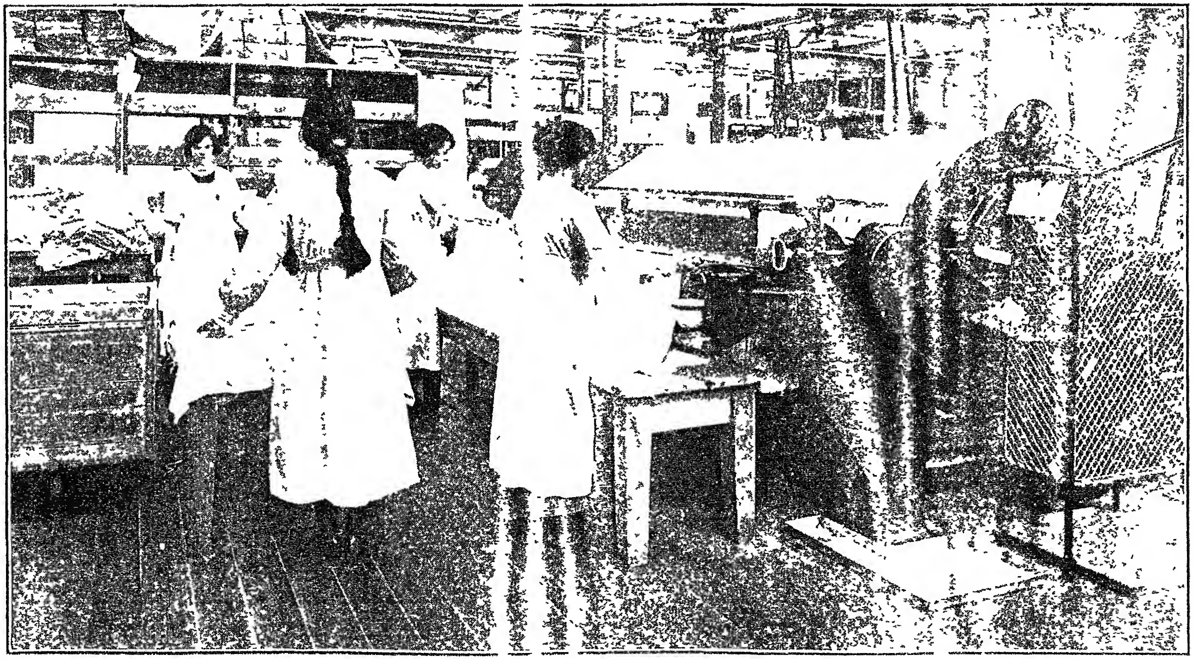

PLATE I.—A Calender, showing the workers placing a sheet. The end of the previous sheet is shown just disappearing. The two girls at the back are preparing the sheets. This machine has a "ribbon feed," so there is no treadle.

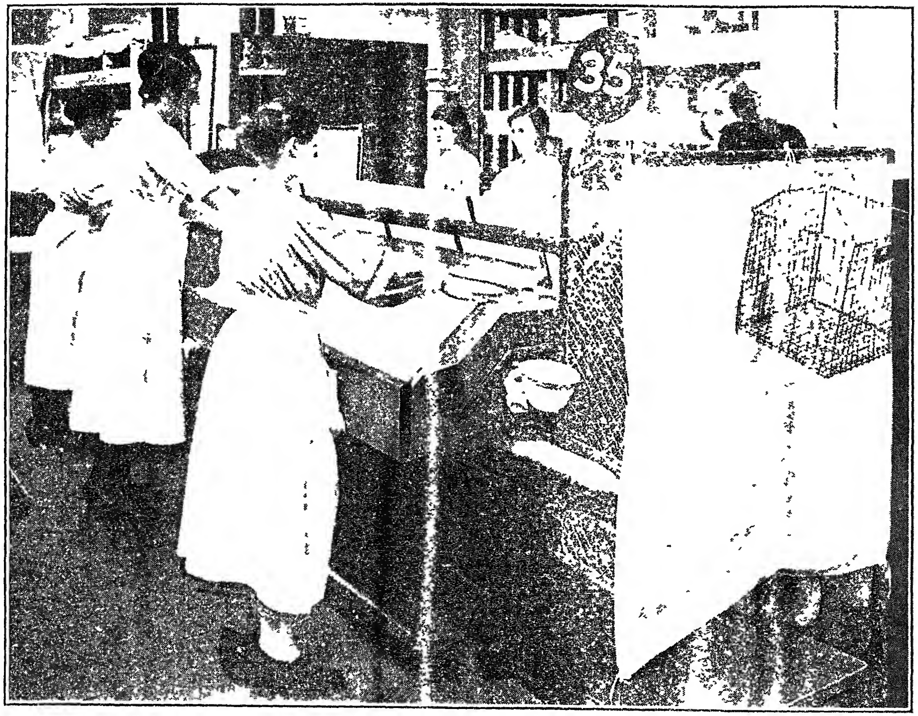

PLATE II.—A Calender with a treadle action. The workers are shown placing a table cloth in position. The end of the previous one is shown just disappearing. The third worker is putting table napkins through. The girls on the right hand are taking off the work.

In order that the measure should be reliable, the following conditions had to be realised :—

(1) The articles were of the same type on all occasions, *e.g.*, this interval would not furnish a fair comparison of one hour with another if on one occasion sheets were being put through, and on another occasion shirts.

(2) There was a constant supply of work on the occasions to be compared, so that the workers were not dawdling at one period because there was little work in evidence and working against time on another.

(3) The manager was either present or absent on all occasions, unless evidence was forthcoming that his presence or absence did not affect the work.

(4) The same standard of work was maintained.

(5) The same workers were operating the feeding of the calender.

(6) The selected articles were in the same preparatory state, *e.g.*, they had all been prepared in the same way.

The articles selected as constants for calender work were (*a*) sheets, (*b*) table linen. These were chosen because all laundries have a fairly regular supply of these articles, and on the whole they vary less than other things.

The method adopted was to time the intervals for 20 successive sheets of the same type and to take the average as indicating the capacity of the worker at the moment (*See* Plates I. and II.) The original intention was to take observations every hour during the working day, but it proved impossible to get all the required conditions fulfilled for this purpose. Laundries differed considerably in this respect, but in many cases only three or four periods a day could be used, one, at about 10 a.m., another in the early afternoon, and another as near as possible to the end of the day. In some laundries, however, almost hourly records were obtainable.

The following will make the method more clear. Time between 8 and 9 a.m. Intervals (in seconds) observed with a stopwatch for 20 sheets* :—

$$\left.\begin{matrix} 4 & 5 & 5 & 5 & 5 \\ 4 & 5 & 5 & 4 & 4 \\ 4 & 5 & 4 & 4 & 4 \\ 5 & 4 & 3 & 5 & 5 \end{matrix}\right\}\text{The average or mean is } 4{\cdot}5 \text{ seconds.}$$

Thus, 4·5 seconds would be taken as representative of the work for the period between 8 and 9 a.m., similar series being obtained as often as possible.

The observations usually extended over a fortnight for each laundry. It might be objected that a longer period is desirable for comparison purposes, but while this is a counsel of perfection,

* Each sheet requires about 30 seconds to pass through the calender, the time varying slightly according to the size of the sheet and the speed of the machine. In the records given these were kept constant.

it is very doubtful if all the conditions would have remained constant for so long. For the purpose of comparison where the general conditions were very constant, records were obtained for five weeks from the calender where the table linen was being done, and almost hourly records were available. The average number of seconds left between the articles for each week for at least seven hours a day were 5·5, 5·8, 5·6, 5·3, 5·5, and 4·8. Hence, where conditions were constant, the weekly variations were so slight as to allow any week to be taken as typical.

Even if many months could have been devoted to one laundry, so as to get many weeks' records, many examples from the ten-hour day would not have been obtained, as during the last year very few firms have had any necessity to work the ten-hour day for more than a short time. However, there are a few records of the ten-hour day worked for a fortnight.

Results obtained.—Laundry I.—During the overtime period the arrangement of hours was from 8.30 a.m. to 12.30 p.m., 1.30 p.m. to 5 p.m., and from 5.30 p.m. to 8 p.m. The normal division of the day was from 8.30 a.m. to 12.30 p.m., and from 1.30 p.m. to 6.30 p.m. The reason alleged for this arrangement was a wish on the part of the workers to begin late, but the almost unbroken period in the afternoon seemed to many to be very long. There was no official recognition of a tea interval during the nine-hour day, but some of the workers did have a cup of tea without leaving their work. The comparison is given in Table I.*

TABLE I.—*Average time interval between 20 successive sheets, based on daily readings for two weeks during (a) a nine-hour day, (b) a ten-hour day period of work. (Laundry I.)*

Hours.	Average Time Intervals (Seconds)			
	9-hour Day Period		10-hour Day Period	
	Average Interval (Seconds).	No of Observations.	Average Interval (Seconds)	No. of Observations.
10 a.m.	7·7	120	8·2	80
3 p.m.	8·9	120	10·3	80
5 p.m.	9·3	120	13·6	120
7 p.m.	—	—	14·9	100
Mean	8·6	—	11·7	—

* It is to be understood that when actual observations are given, they represent rigid conditions for comparative purposes, and involve no other known variable. It would complicate the report too much if all the details of the observations discarded because of other variables were to be inserted

Laundry II.—This firm began work at 7.45 a.m. and continued on till 12.15 p.m. The afternoon spell was from 1.15 p.m. to 5 30 p.m. (and during overtime periods to 6 30 p m.). Officially there was no break for tea, except when overtime was being worked, although actually some of the workers did have a cup of tea while continuing the work. Some of them told me that they rather liked the ten-hour day because there was a stoppage of work for tea.

The machine used for calendering sheets differed somewhat from that previously described, as it had a "ribbon feed," and so there was no treadle action. (*See* Plate II.) The results are shown in Table II.:—

TABLE II.—*Average intervals between successive sheets (Laundry II.)*

Hour	Average Time Interval (Seconds).			
	9-hour Day Period		10-hour Day Period	
	Average Interval (Seconds)	No of Observations	Average Interval (Seconds)	No. of Observations
11 a m –12 noon ..	15·6	200	15·8	200
1–2 p m	13·6	120	14·9	120
2–3 p m . ..	14·5	160	—	—
3–4 p m.	—	—	17·6	120
4–5 p m.	14·0	100	—	—
5–6 p.m.	17·6	100	18·0	100
Mean	15·1	—	16·8	—

Definite conclusions cannot of course be drawn from observations made on so few individuals; but, so far as the data in Tables I. and II. extend, they indicate a general increase in the time interval required on the ten-hour day as compared with the nine-hour day.

These are the only two firms where it was possible to get reliable records of the ten-hour day, worked for at least a fortnight. Most firms have worked an extra hour on a particular day, but this occasional overtime never appeared to have had any measurable effect; on the contrary, the novelty of the arrangement, the break for tea, and the desire to shew what they could do, not infrequently resulted in the last hour being the best. On one occasion, for example, where the average interval from 9 a.m. to 6 p.m., was 8·3 seconds (extremes 7·6 seconds and 9·1 seconds), between 6 and 7 p.m. it was 6·9 seconds, and it was quite obvious that the girls were thoroughly

TABLE III.—*Variations within the nine-hour day in calendering.*

Laundry	Time of Observation. (Weeks.)	Article	Type of Calender	Average interval in seconds between the end of one article and the beginning of the next.									
				8 to 9	9 to 10.	10 to 11	11 to 12	12 to 1	1 to 2	2 to 3.	3 to 4	4 to 5.	5 to 6
A	3	Sheets ..	Treadle action	—	7·7	7·5	7·3	Dinner*		7·1	6·6	6·9	7·3
B.	2	,, ..	,, ,,	—	—	6·2	6·8	6·6	Dinner	6·7	7·4	7·3	6·8
,,	2	,, ..	,, ,,	—	—	7·5	7·0	8·8	,,	—	8·2	6·4	8·2
H.	2	,, ..	,, ,,	—	7·7	—	—	—	,,	8·9	—	after tea 9·3	—
O.	2	,, ..	Ribbon feed	3·2	3·1	3·2	3·2	Dinner	3·2	2·8	3·3	2·8	3·1
G.	2	,, ..	,, ,,	—	—	15·6	—	,,	13·6	14·5	12·8	14·0	17·6
B.	2	Table cloths	Treadle action	—	—	7·5	7·3	7·7	Dinner	7·6	8·0	7·9	9·0
C.	6	,,	,,	5·0	5·2	5·2	5·4	Dinner	5·6	5·4	5·6	5·5	6·0
D.	1	,,	,,	—	—	10·9	—	—	—	9·2	11·1	10·4	—
E	4	,,	,,	—	—	10·1	9·0	8·0	Dinner	9·0	10·0	10·0	10·0
F.	2	,,	,,	—	—	13·0	—	Dinner	13·0	—	14·0	15·0	—
G	2	,,	,,	—	—	—	11·4	,,	10·4	11·8	11·7	14·0	—

* Dinner 12 30 to 2 p.m.

enjoying themselves; but a special appeal had been made as the work was urgent, the other departments in that room were not working, and a totally different spirit prevailed. This condition naturally cannot be arranged to order.

Another point which must be noticed with regard to overtime in laundries, is that if overtime is necessary at all, there is, as a rule, a considerable quantity of work all day so that no relatively slack time is likely to occur, whereas normally there is not quite the same urgency all day. When there is relatively little work, what is done is usually done at a slower rate than normal. In order that the comparison between the nine-hour and the ten-hour day might be quite fair, only those normal weeks when there was an ample supply of work were used.

Variations within the nine-hour day.—Records were obtained from eleven firms working the nine-hour day, the details of which are given in Table III. In all cases the figures represent the time intervals in seconds.

The results shew that there is a very considerable difference in the intervals observed as between the different laundries, even with the same type of machine. Contrast the firm C with firm G, doing sheets on exactly the same type of machine. One reason is the great difference in the way the sheets are prepared for the machine. Not only does inadequate preparing lead to wasted time in the actual handling of the sheets, but also in the opportunity afforded for argument and discussion The actual loss was considerably greater than is reflected here, as the records are given only for that period when the laundry professed to be working steadily. Another probable reason for the regularity of firm C was that this firm worked in spells of two hours followed by ten minutes' rest.

In order to do away with individual differences, for the purposes of finding the hourly variations, it has been assumed that the average for each firm is 100 and the variations have been translated into these terms. The same number of records are not always available for each hour, but 10 o'clock and the afternoon hours between 2 and 6 are fairly representative. Table IV. illustrates this hourly variation for all the firms.

TABLE IV.—*Percentage variations in efficiency within the nine-hour day. (All laundries.)*

Interval (seconds) between one article and the next										
8–9	9–10	10–11	11–12	12–1	1–2	2–3	3–4	4–5	5–6	Mean.
98	98	100	97	98	96	97	102	101	107	100

On the whole the variations were very slight for the ordinary working day, shewing as far as output is concerned little cumulative effect, in the mass. In the case of individual firms there were sometimes larger differences. There seems to be a general tendency for the time interval to increase during the afternoon in the case of firms working entirely without any break.

2.—*Collar Processes.*

As a measure of collar work the time taken to place 50 collars, which had already been " pulled out " ready for steaming on the steaming machine, was observed every hour for three weeks. The type of machine used varies slightly from one laundry to another, but this process is the same for all machines. It is only a question of how many collars the table will hold (*see* Plate III.). A good worker is quick and neat in her movements and alert mentally to detect if there is any mark on a particular collar. From a muscular point of view the work is not hard, and, as a rule, a collar machinist prefers her work to any other laundry work. Laundry workers have often stated that they find collar work very much more interesting than calender work. In some firms, where there is a large collar trade, there is enough work for a girl to be kept collar-steaming all day, other girls being employed in pulling out the collars for steaming, and others again doing the other processes of finishing, damping, moulding, and curling. Other firms on the contrary, keep one or two girls to do all the collar work.

It was possible to get fairly complete hourly records for workers in different laundries. The results are given in Table V.

The spaces represent periods when the worker was either engaged on some other process or the collars were of a different type from that selected for study

Workers A and B are an interesting contrast. They were at the same firm and working under the same conditions Worker A's average for each of the three weeks was practically the same; Worker B on the contrary, while similar to A in the first week, became steadily worse during the next two weeks. She apparently never stopped work, but it was evident that there was some slowing process operating. The actual hour of the day made very little difference to her during the first week, while during the third week she was better during the afternoon. As far as I could discover, the only difference was in herself; the weather at the time (November) was very damp and cold and she suffered quite considerably from " rheumatism " in her shoulder, which she averred became better as the day wore on. This record is valuable as shewing how slight fluctuations of bodily well-being affect the work. It would seem to be self-evident, but factory practice so often ignores this aspect that it is necessary to point it out.

Worker C varied but slightly; when not employed on collar steaming, she was doing other collar processes, chiefly " pulling out " in preparation for steaming For this operation she

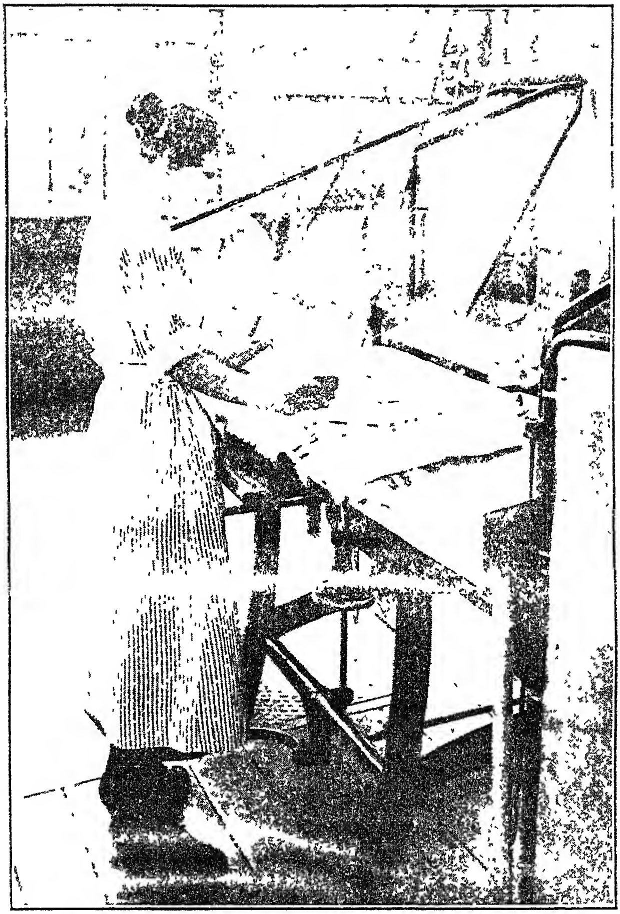

PLATE III.—A girl engaged in "placing" collars for steaming. She has placed three and is in the process of placing a fourth. Note the pile of collars on her right.

TABLE V.—*A Comparison of different workers in collar-steaming*

Hour	Time (in seconds) required to "place" 50 collars.											
	Worker A			Worker B			Worker C.		Worker D	Worker E	Worker F	Worker G
	1st Week	2nd Week	3rd Week	1st Week	2nd Week	3rd Week	1st Week	2nd Week				
8 a m * .	—	—	—	—	—	—	—	—	—	—	—	—
9 a m	140	135	140	120	135	165	—	—	—	120	—	—
10 a m. ..	150	135	140	140	145	160	—	90	165	125	135	—
11 a m	130	145	—	135	135	175	90	80	140	130	150	140
12 a m.	—	—	—	—	—	—	105	—	170	135	150	—
1 p m . .	—	—	—	—	—	—	—	—	—	—	—	110
2 p m	120	125	—	120	145	160	100	105	—	125	—	—
3 p m	—	130	130	—	135	140	120	100	150	125	170	125
4 p m	—	130	135	120	135	140	100	100	140	130	155	—
5 p m . ..	135	155	130	130	145	150	—†	—†	125‡	125	155	—
6 p m . .	—	—	—	—	—	—	—†	—†	145	—	—	—
Mean .. .	135	136	135	128	139	156	103	95	148	127	152	—
Time of observation (days) ..	12			12			10		5	10	10	5
	Only 4 days a week worked											

* No records. † No collar steaming after 4 p m ‡ After tea.

always sat down, so that her day was spent alternately sitting and standing, a state of affairs which had her hearty approval.

Worker D was interesting as a type of the erratic worker; she had spasms of lethargy followed by an almost explosive outburst of energy. The records here utilised were from those when she was working fairly regularly, so her variations as given really mask much greater ones.

A rather more detailed study of this worker is instructive. In order to place 50 collars it was necessary, as the machine used only held about eight at a time, to get records of several series in immediate succession, so that a typical record would be as follows:

8	collars in	24	seconds	= 3·0	seconds	a collar.
6	,,	,, 26	,,	= 4·5	,,	,,
6	,,	,, 21	,,	= 3·5	,,	,,
10	,,	,, 30	,,	= 3·0	,,	,,

Now, assuming that all the collars were of equal difficulty, a series of batches done in immediate succession should work out at approximately the same time for each collar. It is usual to express this variation for purposes of comparison as a percentage variation. The more regular is the worker, the less the variation: the less regular, the greater the variation.

On one day this particular worker was very regular, and her variations from her own average at different times of the day were as follows:—

Hour.	*Average Time to Place one Collar* Seconds.	*Percentage Variation*
10.40 a.m	3·5	18
11 40 a m...	2·3	17
3.20 p m. ..	2·2	11
4 20 p m	3·4	10
6 0 p m	2·5	19
7 15 p m	2·0	16

Contrast this with a few days later:—

11 30 a m ..	2·7	27
3 35 p m. ..	3·3	16
4 15 p m ..	2·9	46
5 15 p.m	2·7	33
5.50 p.m. ..	2·3	17

It will be noticed that this second day was characterised by much greater variability. On the whole her variability was very much greater in the afternoon. The morning range is from 16 to 28 per cent., whereas the afternoon is from 17 to 46 per cent. A possible cause of this difference in the case of this girl was the menstrual period, though in other instances no such result was obvious.

The time of day in the case of such a worker really is not representative; actually she worked more quickly in the afternoon, if one considers only the average rate per hour given above, but she worked less regularly, and it seems a fair assumption that she found it more difficult to fix her attention.

Workers E and F showed a tendency to fall off towards the end of the morning, but the afternoon gave little indication of the time of the day. The morning period was one of five hours unbroken, while the afternoon period was four hours broken by a period for tea.

Records from other firms were of a similar nature. This process is one which seems to have been standardised more than any other, and on the whole the hourly variations are very slight.

The other collar processes were so frequently done by different girls, that it was only occasionally possible to get enough carried out under precisely the same conditions.

Two girls at one laundry doing collar-curling gave the following average records for a fortnight. At 10 o'clock they took 210 and 215 seconds respectively to curl 50 collars; at 3 o'clock 210 and 220 seconds; and at 6 o'clock 225 and 245 seconds. The afternoon spell was one of five hours. They were not doing this work all day. On the whole, there was a slight tendency for the afternoon to be a little slower than the morning This variation, however, which seems so small, must be estimated comparatively for the whole week, when the accumulation of a few seconds here and there on short timed processes becomes considerable.

3—*Smoothing by means of the Press.*

The press is a machine by means of which large surfaces can be smoothed. As in the case of other machines, hourly output could not be computed owing to the wide diversity of the articles done on it, as well as to the variation in the dampness of the articles. Overalls, dresses, bed-sides, shirts, waitresses' aprons, chefs' coats, and surplices, are all practically done on this machine, and this bewildering variety prevents adequate measure.

In order to get some measure of output for the purpose of noting the hourly variation, if any, the actual output was taken every hour for five weeks, of the one class of work which appeared most frequently, *viz.*, chefs' coats. When general conditions were the same, the number done in an hour was very regular, as will be seen from Table VI.:—

TABLE VI.—*Hourly output variations in smoothing.*

Average Number of Chefs' Coats "Smoothed" in an Hour.									
8–9	9–10	10–11	11–12	12–1	1–2	2–3	3–4	4–5	5–6
17	18	18	18	Dinner	16	16	16	17	16

It will be seen that the afternoon rate was slightly slower than the morning rate. The reason may be the time of the day, but

was in the hottest part of the building and reference to the temperature records given below will shew that the temperature gradually rose and the cooling power of the air decreased as the day went on (*see* p 38).

In another firm, the time taken to bring down the lid ten times in succession, for as many hours of the day as allowed of comparable conditions was used. This was obtained by timing ten successive operations of the press and subtracting the time during which the lid was in position (*see* Plate IV.). The article being done was workmen's overalls. This worker was an elderly woman, who took a great pride in her work and was one of the few people I met who had a feeling of attachment for this machine. Her output from the point of view of the firm was considerably greater than that of the other "press" workers. She was the type of worker, who, if she felt tired or disinclined to work, would force herself to work harder. Hence, it seems fairly safe to assume that any variation in her rate of work would be involuntary.

TABLE VII.—*Individual variations in performance within the ten-hour and nine-hour day (Smoothing).*

Length of Day.	Average Time (in seconds) to bring Lid of Press down 10 times		
	Morning. (10–11 a m)	Early Afternoon (2–3 p m)	Late Afternoon (5–6 p m)
10 hour	7·7	7 8	11 4
9 hour	7·9	8 4	11·1

It will be seen that there was very little difference between the first two periods, but during the late afternoon there was a considerable increase in the time. A subjective sensation which she experienced towards the end of the day, was that the lid seemed heavier. As the firm paid particular attention to the balance of this machine, it seems probable that the extra weight really referred to her own growing weariness.

Another worker was of a quite different type. She worked erratically and was not averse from taking any favourable opportunity for leaving her work. She was also liable to fits of contemplation, during which she kept her hands on the handle of the press, without bringing the lid down for several minutes If these had invariably occurred at the same hour or period of the day, they might have been worth investigating, but they were evidently dependent on conditions unconnected with the time of day. I

PLATE IV.—A Press used for smoothing the soft plain parts of such articles as aprons, overalls, coats, etc. The worker has her right foot on the right hand treadle and with her arms she is bringing down the lid. As she closes the right hand lid the one on her left, now closed, automatically opens. She performs this action on an average about every 15 seconds, with a longer interval when she has finished one article.

did not include those contemplative exercises in the records, although actually they accounted for much lost time. There are records for three weeks of this worker, during which period she was working the usual nine-hour day.

TABLE VIII.—*Individual variations in performance within the nine-hour day. (Smoothing.)*

——	Morning	Early Afternoon	Late Afternoon
Average time (seconds) to bring the lid down 10 times	11 0	14·1	11·2

About 4.30 she had tea, after which she invariably settled down to a period of steady work.

In the case of another worker in another firm, the records for one week are as follows :—

10 a.m.	12 seconds.	
2–3 p m.	12·2	,,
4.30–5.30 p m.	14·7	,,

This worker showed a lengthening of the time taken during the late afternoon This firm allowed no break for tea, the afternoon period being from 1 to 5.30, and the supervision was such that it was impossible for the worker to go away and enjoy a surreptitious cup of tea and rest.

Comparison of these workers seems to shew that there was a gradual lengthening of the time taken to perform the operation as the day wore on, and that individuals varied as to where this set in , one worker was quite obviously worse during the early part of the afternoon.

4.—*Folding of Sheets and Table Linen.*

This process is entirely under the control of two workers, except in so far as they must keep up with the work and not delay the packers. They have not, however, to adjust to a machine It is a graceful action and demands no cramped movements ; it is one that must be performed standing.

Owing to the considerable divergence in sizes of sheets and table linen, recording of the hourly output was impracticable. It was therefore decided to take, at as many hours of the day as admitted of comparable conditions, the time required to fold a sheet or table cloth based on an average of 20 articles in immediate succession (omitting any abnormal article).

Firm A.—Records are available for three weeks, during one of which a ten-hour day was worked Unfortunately, the supply of the same type of table cloth was not available every hour.

The average time (in seconds) taken to fold a table cloth at different times was as follows :—

TABLE IX.—*Individual variations in performance within the ten-hour and nine-hour day. (Folding.)*

Length of Day	Morning.	Between 2 and 3 p m	Between 5 and 6 p m.
10-hour	22·0	21·6	25 3
9-hour (1)	20·2	20·0	22·9
9-hour (2)	19 4	19·5	22·5

It will be noticed that the average time varies very slightly for the two nine-hour day weeks. The ten-hour week, during which observations were made, was the last of several involving overtime work, so that it is uncertain whether the difference in the morning period was due to the cumulative effects of several previous weeks or not This firm allowed tea to be drunk while working, but there was no cessation of work.

Firm C.—From this firm four weeks' records were obtainable for at least seven hours of the day. The average times for each of the four weeks are 15·8, 15·5, 15·3 and 15·3 seconds. The two girls whose records were obtained were of the same height and type, both energetic, eager to get on with the work, and liking to work together ; they generally managed to get into a rhythmic movement, which they could keep up for some time, and which was only broken when some table cloth required special scrutiny or special attention, owing to its condition. They worked extraordinarily well and practically never stopped during working hours.

This firm allowed a rest pause of 10 minutes at 10 a.m. and again at 3 p.m., on both of which occasions the girls left the works. According to the time of day, the details are as follows :—

Hour.	*Seconds.*
8 to 9 a.m.	15·7
9 ,, 10 ,, ...	15·3
(10 ,, 10.10 a.m., rest pause).	
10 ,, 11 a.m.	15·2
11 ,, 12 noon.	15·5
(12 ,, 1 p.m. dinner).	
1 ,, 2 ,, ...	16·0
2 ,, 3 ,, ...	15·1
(3 ,, 3.10 p.m., rest pause).	
3 ,, 4 p.m.	15·1
4 ,, 5 ,, ...	15·7
5 ,, 6 ,, ...	15·6

It will be noticed that the period between 8 and 9 a.m. and that between 1 and 2 p.m., although beginning periods, were not quite so good as later stages ; this is due to the fact that the

workers had not quite got into their usual rhythm. There was also slight falling off during the period after 4 o'clock.

A very similar result was shewn by another firm, working, however, only a four-day week :—

Hour.	*Seconds.*
8 to 9 a m.	no records.
9 ,, 10 ,,	15·8
10 ,, 11 ,,	16·1
11 ,, 12 noon	16·5
12 ,, 1 p.m.	16·3
1 ,, 2.30 ,,	dinner.
2.30 ,, 3 ,,	16·2
3 ,, 4 ,,	16·3
Tea interval.	
4 ,, 5 ,,	16·3
5 ,, 6 ,,	17·2
6 ,, 6 30 ,,	16·9

The general remarks about the workers made with regard to Firm C apply also here, and there is an astonishing agreement especially to be noticed when one considers that the workers were different, and that the two firms had no connection with one another. This firm allowed tea in the morning without leaving the work, but in the afternoon the workers sat down for about a quarter of an hour in the works, and had tea if they wished.

5.—*Hand Ironing*

Firm A.—With few exceptions every shirt was ironed as far as possible on machines, only the final finishing off being done by hand. As a measure of the work, the average time required by the hand ironer to finish off five shirts in immediate succession was taken, the shirts being soft ones with double cuffs. When there were no shirts to be done, this ironer was engaged in ironing other garments. It was possible to get three weeks' records, during one of which a ten-hour day was worked. When these records were obtained, overtime had already been worked for some time. The data are as follows :—

TABLE X.—*Individual variations in performance within the ten-hour and nine-hour day (Hand ironing.)*

Length of Day	Average Time (in seconds) to finish off a Shirt							
	10 to 11.	11 to 12.	12 to 12 45.	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6
10-hour ..	78	—	—	—	77	—	—	86
9-hour ..	52	62	63	—	64	56	58	65

This worker was young and a very regular worker. She had a cup of tea sometimes, but drank it quickly and hardly stopped. Her records shew a falling off during the ten-hour day, and during the nine-hour day, a slight deterioration in the afternoon. She was interesting to watch from this point of view, for as the day went on she became gradually more fussy with regard to her work, tending to be less satisfied and giving an ultra-scrupulous attention to unnecessary detail. She herself was quite unaware of this difference.

Firm B.—The type of shirts was the same as that described above under Firm A, but very much more was done by hand by this worker. Here no time was allowed for extra meals and it was impossible for the workers to get even surreptitiously a cup of tea.

There is a record of only one week, but a fairly representative number of observations were available. The average time in seconds to iron a shirt is given :—

11 to 12.	1 to 2.	3 to 4	4 to 5.
344	—	432	429

Here there seems to be a gradual lengthening of the time taken as the day progresses. The ironers here practically never left their boards, the work being brought to them regularly, and there was very careful supervision of this department.

Firm X.—Here the amount to be ironed by hand was intermediate between the two firms given above (more machine ironing being done in Firm A and less in Firm B), and the standard of work was high. Records of four workers for at least a fortnight are given in Table XI.

TABLE XI.—*Individual variations in output within the nine-hour day. (Hand ironing.)*

Worker.	Length of Day.	Average Time (in Seconds) to iron one Shirt.								
		Morning Period, 8 a m –1 p m				Afternoon Period, 2 p m –6 p m.				
		9–10.	10–11	11–12	12–1	2 30–3	3–4	4–5.	5–6	6–7.
I.	9 hrs	—	229	—	267	218	—	210	226	—
II	,,	—	218	—	—	247	—	225	266	—
III.	,,	—	279	—	—	—	—	—	307	—
IV	,,	—	213	—	212	202	—	213	217	—
Mean ..		—	235	—	—	222	—	216	253	—

This table shews the very considerable individual differences, as well as the increased time taken at the end of the day.

III.—THE EFFECT OF REST PAUSES

It is customary in the laundry trade to divide the day into two periods of five hours and four hours, or four hours and five hours respectively. Certain firms (but these seem to be in the minority) allow an interval for tea in the afternoon, and some also an interval in the morning. The usual objection raised by opponents of the definitely specified rest pause is, that the work involves so many involuntary pauses during the day, due to the variations in the flow of work from department to department, that a voluntary one is unnecessary. These involuntary rest pauses due to the stoppage of work are, however, rather sources of irritation than beneficial rests, and, moreover, people usually prefer a definite time recognized as their own, to a doubtfully occurring time dependent on circumstances they cannot control Some firms, too, are sufficiently well organized to have very few of these irregular stoppages. A reference to the table of calender intervals given on p 8 will shew that the records of Firms A and C are very regular.

Firm A was only working four days a week, but during working hours there was practically no time lost, as the object was to finish the week's work on Friday night. A tea interval of about fifteen minutes in the afternoon, during which time the girls stopped work and sat down, was recognized, in addition to one and a half hours for dinner.

Firm C worked quite definitely in two-hour periods, a break of ten minutes being allowed at 10 a m. and again at 3 p.m., when the girls left the work and either sat down in the garden or rest room, or had tea in the canteen. The regularity of the work here was particularly noticeable. The ten minutes period was never abused, the girls returning quite regularly to time. Actually this definitely permitted rest pause involved less time than the more casual methods of many firms In some places, tea was brought round to the workers, who were not supposed to stop work , in others they took it in turns to go and make tea; in others no one was supposed to have tea, but the fact that this was done was connived at; in others, no opportunity was given for even a surreptitious cup of tea. It was certainly much appreciated where it was allowed.

I am inclined to think that some of the advantages are of a psychological character, rather than due to the stimulating action of the tea. We can face with equanimity, and even with enthusiasm, a period of two hours' work with the prospect of a rest, but to look forward to four or five hours' work unbroken, is likely to damp the enthusiasm of even an ardent worker. The result is a good deal of unrecognized wasted time which actually is difficult to record.

In this connection the following variations in these intervals are worthy of consideration. In timing two "feeders" about 5 o'clock one afternoon, the intervals (in seconds) were found to be as follows :—

6, 8, 8, 7, 25, 21, 18, 8, 6, etc.

A scrutiny of these figures shows that the possible standard ranged between six and eight seconds; the long intervals represented not difficult sheets nor badly prepared sheets, but a period when the article remained poised in the air while a conversation was conducted. Nor was this an isolated case occurring late in the afternoon; in this particular firm such records occurred quite frequently at any time of the day and had to be omitted in dealing with the records, as they could not be said to represent the effect of the hour of the day.

Occasionally time was lost through the girls falling into a dreamy quiescent stage, known to psychologists as the state of dispersed attention. This tended to occur towards the end of the day, and was probably due to the effect of the hours spent in a high temperature with insufficient air movement (cf. p. 39). It was quite possible to converse and work.

Contrast the above records with the intervals (in seconds) taken in another firm at the same time of the day :—

5, 6, 5, 5, 6, 5, 7, 5, 5, 5, 5, 5, etc.

This firm worked in periods of two hours followed by ten minutes' interval, and during eight weeks there were no records to approximate to the type given previously. It is to be understood that in both cases there was plenty of work to be done; the loss of time was entirely due to the girls, nor was it likely to be detected without the use of a stop watch.

It is unnatural to maintain unchanged absolute regularity, but it is also wasteful to keep machines running for no purpose; to work hard while working and then to rest for a definite period would probably prove beneficial both to the worker and the machines.

In the case of a hand ironer, a special study of the effect of a rest was made. Table XII. represents the average time taken to iron one shirt (soft double cuffs), the average being computed from a measure of five done in immediate succession.

It will be noticed that during the last hour the time taken is longer, though the worker herself was not aware of this; in fact she often said that the time of day made no difference to her, and that however tired she was she could still keep up the same rate. The table given above is an interesting commentary on the value of purely subjective opinions. She said she felt tired when overtime was worked, and that her feet ached badly. I was, however, quite unable to detect by observations in what the lengthening time consisted; she did not, as in the case given above, make unnecessary additions to her work, but apparently just slowed down.

TABLE XII.—*Variations in output throughout the week without rest pauses.*

Hour	Average Time (in seconds) to iron one Shirt [1]					
	Mon.	Tues	Wed	Thurs	Fri.	Average
9—10 a m	—	201	—	—	209	205
10—11 a m ..	—	—	199	206	—	202
11—12 a m ..	199	—	—	224	—	211
12—1 p m ..	220	215	199	211	—	211
1—2 p m		(Dinner)				
2—3 p m ..	171	175	173	174	174	173
3—4 p m .	192	205	201	211	—	202
4—5 p m. ..	—	—	—	—	208	208
5—6 p m ..	—	—	210	—	203	206
6—7 p m .	—	241	233	270	231	244

[1] Where there are blanks it only means that the worker was ironing shirts of a different type, or that the conditions were in some way not comparable

There is one other feature of interest about this table. By good chance, all that week she was doing this particular type of shirt at 2 p m., immediately after the midday rest. On every day there was a distinct improvement in the time taken, indicating the beneficial effect of the rest.

I was unable to get records with her during the first hour in the morning, but the week after the records given above, the firm introduced a fifteen minutes' rest at 10 a.m., with the result shown in Table XIII

TABLE XIII.—*Variations in output throughout the week with rest pause*

Hour of Day	Average Time (in seconds) to iron one Shirt					
	Mon	Tues	Wed.	Thurs	Fri	Average.
8—9 a m ..	—	No records		—	—	—
9—10 a m	—	235	216	203	187	210
10—10 15 a m		Rest				
10 30—12 a m	—	173	194	195	160	180
12—1 p m ..	—	210	206	190	214	207
1—2 p m ..		Dinner				
2—3 p m.	—	170	—	173	167	170
3—4 p m .	—	—	204	182	—	193
4—5 p m ..	—	—	—	204	—	204
5—6 p m ..	—	230	222	—	206	219

It will be noticed that again the 2 to 3 p m period was the best, and that there was in each case an improvement after the fifteen minutes' rest.

It was hoped to discover exactly where she began to fall off, but unfortunately the supply of the one type of shirts did not permit of it, and the very great variations in starched shirts, and the special attention devoted to some of them, made them unreliable for statistical purposes

It certainly would appear that the rest pauses were beneficial to this worker. Hand ironing is much more dependent on the individual worker than other processes in the laundry, and hence any individual change is likely to be reflected in the work.

IV.—INDIVIDUAL VARIATIONS.

So far we have been concerned with bringing out such variations as may occur during the ordinary working day. We have seen that in cases where the ten-hour day was in operation for several days on end, there is a tendency for the later part of the afternoon to be less effective than the morning or earlier afternoon, and that the same tendency reveals itself in some firms where no extra time is being worked.

1.—*Calender Work.*

Another factor which is also important is the variation in work which is due to the individual worker. In calender work one would naturally expect the leader to have an influence on the speed of the work, and there is an idea among some launderers that she is all-important. The following observation, showing the influence of the subordinate, is interesting. It must be noted that she was not a beginner, but an expert calenderer and accustomed to the machine.

In a firm where seven weeks' records were obtained, the average hourly interval for six weeks was about five seconds, the measure being the time interval as described above During one week, when the assistant was absent, another calender girl took her place ; that week was exceptional with a variation from 5·8 to 7·6 seconds, nor was the pace so regular. It was easy to see that the second girl was always just a little behind the leader in fixing the article on the calender, probably due to a natural slowness of movement, though neither of them was conscious of the fact. The second worker was rather clumsy in movement, whether due to natural awkwardness or inadequate instruction when learning the work, it is impossible to say.

In another case where the average interval was 9 seconds, the change of assistant increased the interval to an average of 15 seconds.

2.—*Folding.*

As this is a process entirely under the worker's own control, individual differences are more noticeable than where a certain adjustment to a machine is necessary. The ideal folders are two girls, either tall or of medium height, whose movements fall into rhythm. If a girl is too short then in folding a fairly large article, she tends either to lift her arm too high for personal comfort (which eventually tires her unnecessarily by making her shoulders ache), or else she is likely to drop a corner of the sheet on the floor, which will necessitate at the very least a careful scrutiny, to see if the corner which has touched the floor shews any sign of its

accident (and with most floors it certainly would), and in the worst cases will involve re-washing. It is obvious that the work is interfered with, and in the case of these apparently trifling accidents, not only is there the delay actually demanded by the work, but an opportunity arises for an argument or extra conversation, which in the absence of such delay would not have suggested itself. On one occasion some information on this point was available. A tall folder of sheets worked sometimes with a girl of her own height, and sometimes with a considerably shorter one, both being experienced folders. The average time taken to fold 20 sheets with the tall partner was 21·4 seconds, but was increased to 24·6 seconds when her partner was the short girl.

The additional delays through accidents have not been calculated; but they were considerable and varied from firm to firm.

A similar difference was noticeable in the case of two other girls folding table cloths. Several records at different hours of the day are given, the figure being the average time (in seconds) taken in folding a table cloth of uniform size.

TABLE XIV—*Effect of team work on output variations.* (*Folding.*)

Team.	Average time (in seconds) to fold one table cloth			
	11 a m.	2 p m	3 p m	5 p m
Worker A. with B	16·3	14 9	16·6	15·1
Worker A with C	22·0	19 2	18 1	18·1
Worker A with D	16·1	14·9	15·3	—

All the workers were experienced folders. There is no doubt that some people work much better together than others, and it is, therefore, surely a matter of some interest to find out which girls actually work well together and arrange accordingly.

3.—*Hand Ironing.*

A reference to the table given on p. 18 will shew that there were individual differences in the time taken to perform a certain piece of work at a given time of day, as well as in the reaction to the effect of the work. In the case of four hand ironers, for instance, working under the same general conditions and engaged on the same type of articles, the average times required to iron five shirts between 10 a.m. and 11 a.m. were 229, 218, 279, and 211 seconds respectively.

Apparently the quality of each person's work reached the desired standard, yet there was considerable difference in the time taken to iron a shirt. This difference was not due to inexperience, for all were expert shirt ironers. The general method of dealing with the shirt was the same. To an observer, however, the differences in bodily movements of these ironers were interesting; for

some ironed with the whole of the body in action, whilst others gave the impression of relative immobility. It was quite obvious that many of the movements were unnecessary, and if not actually a hindrance to the process, still not a help, thus involving a loss of energy. Some workers appeared to use the proper muscles and to expend only such energy as was necessary for the success of the work, but to labour under a constant incapacity to make up their minds that a shirt was done; they went over a finished surface unnecessarily and seemed reluctant to consign the article they were doing to the finished pile. Others again were naturally very slow of movement, and under present conditions ought not to have been ironing, if rapid output was a desideratum.

4.—*Sorting.*

With this process, it was never possible to get a satisfactory number of records at different hours of the day; the varying amount of attention required by different articles, the constant stopping to check, and the necessity for referring to the head of the department, prevented any really comparable measure. I was able, however, to study the different rates at which three different girls worked, when working under the same conditions. For this purpose, the measure taken was the time required to sort 100 articles of the same type, and in the course of a week at least 10 different series of 100 each for three girls, were obtained. The variations are suggestive. Two of the girls were sisters; their range of variation was from 15 minutes to 19 minutes to sort 100 articles, and the other girl ranged from 19 minutes to 31 minutes.

These individual differences are interesting as shewing the importance of suitable selection of individuals for the work. From a close observation of the three girls, one could not say that mere slowness of actual bodily movement was the sole cause; the slow girl could move quickly and she was a particularly rapid and reliable packer. She certainly "sorted" untidily, but I am inclined to think that the emotion of disgust was at least a contributory factor; her facial contortions at unusually dirty articles and the extremely careful way in which she sought out the least dirty part of an article, shewed that she had not become sufficiently habituated to the process, in spite of long experience, to have become indifferent. Some girls frankly admit that they very rarely consider any article from the point of view of cleanliness; to them the only problem is to decide to which category it belongs *

In accuracy there was little to differentiate the three girls, but their variations in speed would obviously make a difference to the firm when calculating its output, and in the case of piece work to the girl herself.

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* From the point of view of psycho-analysis, these individual differences have probably a more deep-seated origin, but the discussion would hardly be pertinent to this inquiry.

V.—STUDIES WITH A PSYCHOLOGICAL TEST.

1.—*Method Employed.*

As the measurement of output proved so difficult in the laundry trade, an attempt was made to measure the effect of the work on the worker by means of a test having nothing to do with the actual work. The test selected was that known as the " dotting " test. The machine was invented years ago by Dr. McDougall and modified by Dr W. H. R Rivers, and is a mechanical device whereby a continuous band of paper tape about one inch wide, is drawn behind an opening or window in the top of a desk, by a weight-driven clockwork movement. Along the width of the band small red circles are distributed in as irregular a manner as possible. The test consists in marking the red circles with a stylographic pen as they pass before the subject's field of vision.

The test is quite exciting, and the majority of people find it a real stimulation to do their best. As it involves continuous attention, the better the attention, the fewer mistakes will occur, and as one's powers of attention are affected by such psychological changes as are caused by fatigue, it is an indirect test of fatigue.

A length of tape two metres long was the standard amount. On this were 400 small circles, each of which had to be dotted with a stylographic pen ; most of the girls worked at a rate of four dots a second. Each performance of the test only kept a girl away from her work for about three minutes in the morning and the same time in the evening. As I was primarily concerned with the problem of the effect of the day's work, I could only have as many subjects as could be experimented on in an hour ; 15 were found to be the most convenient number. Each girl came and did the test between 9 and 10 a.m., and again between 5 and 6 p.m As far as possible, five weeks' records were obtained from each, of which only four were used, so that any one week when illness or some untoward condition caused considerable variation could be omitted. These variations (which will be discussed later), though they are extremely interesting when the number of subjects is few, can cause considerable disturbance to an average.

For the purpose of the experiment, the machine was placed in a quiet corner of the laundry. Theoretically it might be assumed that a test requiring attention should be done in the quietness of a secluded room, but in a laundry, as a rule, no such room exists ; and even if it did, it seems desirable from a practical point of view that the test should be done under factory conditions ; also much less time is wasted in coming and going when the whole course is under observation. The machine was, however, sufficiently isolated to prevent anyone from observing the actual dotting or overhearing any conversation between the subject and the experimenter.

The writer had had considerable experience with this test under laboratory conditions, and had been able to shew that it was definitely susceptible to changes in the body resulting from loss of sleep, ill-health, and certain drugs.*

2.—*Individual Variations.*

Before describing some results with factory girls, it is necessary to emphasize that the human being is a whole, not something which can be divided off into the factory worker and the rest. It therefore follows that the whole life is background to the work. In doing tests in a factory, whether we use "output" or a "fatigue test," we have to assume that this background remains constant during a working day or week. Actually this is not so, for although it is true, roughly speaking, that home conditions, for example, remain constant during the day, the workers' thoughts about them do not. Also, there are emotional changes which vary irregularly and affect differently different individuals, *e g.*, some people are stimulated by anger, others depressed; nor must we overlook the fact that there are fluctuations in bodily health, which while not sufficiently great to cause definite illness, may yet be sufficient to make a normally easy task a very difficult one. Hence we may get on some occasions a striking apparent fatigue effect at 6 o'clock, which, however, is only a fatigue effect under these conditions. It must be remembered that fatigue is the expression of a relation: a relation between the amount of energy at the disposal of the worker and the work being done; some people, therefore, will be able to work easily a factory day without any indication of fatigue, whereas others will shew marked signs of it. Hence, in using a test of a sensitive type, the experimenter will tend to measure other variable factors as well as fatigue. As, however, these will also affect the success of the ordinary work, it is desirable that they should be known.

It is probably a fairly safe assumption that, if in the case of a given worker there is on most occasions a considerable increase in the number of errors at night as compared with the morning, the difference represents the effect of the intervening number of hours, part of which is the effect of the work. It might be argued that if a worker wishes to prove that her work is fatiguing she will do her best in the morning and try to do badly in the evening. This is certainly a possibility and must not be overlooked; but we must remember that the average human being trying to make a case out for himself tends to overdo it. The subjects of the experiment did not know how many mistakes they had made on a given occasion, and to be able to arrange with such a test to make a due, but not excessive addition to the morning errors every evening, would be to have powers which my experience has never encountered. Also, while a girl generally knows if she is doing it badly, she quite often thinks she is doing it very well when the record is to the contrary.

* "A Contribution to the Study of Fatigue," *Brit Journ. Psych* **8,** *3*
"Effect of Alcohol and some Other Drugs during Normal and Fatigued Conditions." *Medical Research Council, Spec Rep Sec No 56.*

In starting the experiments, three days were always allowed to go unrecorded so that the girl might become accustomed to the experiment and the novel conditions, and also get over some practice effect. It sometimes happened that she was unable to come to me, owing to the exigencies of the work.

Some detailed individual studies will best illustrate the method.

Case I.—Table XV. gives the results for a wash-house girl.

TABLE XV.—*Diurnal variations in "dotting" errors.* *(Wash-house girl.)*

Day.	No of Errors		Remarks
	Morning, 8—9	Afternoon, 5—6	
(1) Thursday ..	7	No records	—
(2) Friday ..	20	,,	—
(3) Monday ..	No records	,,	—
(4) Tuesday .	21	21	Easy day
(5) Wednesday..	29	45	Very worrying day; not very well.
(6) Thursday .	20	33	,, ,, ,, ,, ,, ,,
(7) Friday .	11	30	,, ,, ,, ,, ,, ,,
(8) Monday ..	23	—	—
(9) Tuesday ..	10	48	Better, but worrying day.
(10) Wednesday.	12	—	,, ,, ,,
(11) Thursday ..	15	37	,, ,, ,,
(12) Friday .	10	42	,, ,, ,,

It will be noticed that her morning records are better than the afternoon records, although in one case (4) the afternoon is as good as the morning. That day she described as easy. The days described as worrying, were days when for some reason many things were sent back to be re-washed. Her remarks on her day's work were usually spontaneous, although if she made no remark I asked her, by way of conversation, what kind of a day she had had.

Compare this with another week, when there was comparative freedom from extraneous factors :—

TABLE XVI.—*Diurnal variations in "dotting" errors.* *(The same girl.)*

Day	No. of Errors.	
	Morning	Afternoon
Monday	6	—
Tuesday	7	8
Wednesday	13	16
Thursday	23 (very busy)	20
Friday	8	6

Thursday was a busier day than the others, but not worrying. It might be argued that she had now become used to the experiment, and so the machine failed to record changes in her bodily well-being, but the following week shews that such was not the case :—

Table XVII.—*Diurnal variations in "dotting" errors.*
(*The same girl.*)

Day	No of Errors	
	Morning	Afternoon
Monday	10	10
Tuesday	20 (slight accident)	13
Wednesday	18	8 (feels quite right)
Thursday	56 (hurt her head)	43
Friday	30	19

These results shew how very much fatigue investigations are affected by various factors. These accidents were not of such a nature apparently as to interfere with the prosecution of her work, yet they affected the test; and it is a likely assumption that they would also affect her work, in so far as that work involved other than mere routine.

Practically every case investigated involved a similar set of variations, though fortunately not always so many with one person.

Case II.—One girl almost invariably had a headache in the morning and was dull and heavy. Her general appearance would suggest anæmia. Her records for three weeks are given in full :—

Table XVIII.—*Diurnal variations in "dotting" errors.*
(*A girl subject to headache.*)

Week	Number of Errors									
	Monday		Tuesday		Wednesday		Thursday		Friday	
	M	A	M	A	M	A	M	A	M	A
1st ..	29	29	27	30	*44	16	16	40	25	—
2nd	36	23	*48	26	24	30	30	35	18	16
3rd	21	28	13	10	14	—	16	25	19	13
Average ..	29	27	29	22	23	23	21	33	21	15

Thursday was her day of greatest pressure as far as the work was concerned, which seems to be reflected in the increased number of errors in the evening. On the other days there is little difference between the morning and afternoon periods, but we could not,

therefore, infer that no fatigue was present, for any measure of her work in the morning involved at least the effect of her headache and in the afternoon the effect of the hours she had worked, neutralized by the absence of the headache. During the third week she was taking a tonic and she volunteered the information that she was feeling better. On the two mornings marked with an asterisk, she told me her head was very bad.

Case III.—Some girls are very much affected by the way in which the work has to be done. If all goes well and they can work without pressure, they will maintain a regular and successful standard. It happens, however, not infrequently in laundries that some department has to rush in order to keep up with another, probably the most usual place being the packing room when the carmen are waiting to take out the work. In these circumstances, some girls quickly shew the effects, even though they think they have maintained their usual standard of work It was not practicable to find out how many mistakes were made in the work, but the dotting very quickly reflected the mental perturbation in some people.

One girl, a very good packer, used to give very regular dotting records. For three weeks her morning range of errors lay between 8 and 19, her afternoon range between 13 and 22. On two Fridays and one Thursday, she was working not longer hours but much more intensely, as she was all day working against time. Her records on one Friday increased from 17 in the morning to 49 in the evening ; on another Friday from 13 in the morning to 48 in the evening, and on Thursday to 37. That these results were not merely due to the effect of the end of the week is shewn in another week, when on Thursday morning she had 11 errors and Thursday evening 18, on Friday 10 and 13.

Case IV.—In the case of another packer the effect was similar. She was a girl with considerable vitality and showing a great interest in her work. Under normal conditions her variations for the morning period were from 33 to 48, for the afternoon from 33 to 66. On one Thursday morning she was working against time and had been doing so for two hours before she came to me ; her errors on that occasion were 88, by the afternoon she was working less strenuously and her errors fell to 68, and on the following day they were 36 and 44 for the morning and afternoon period respectively. Monday morning went smoothly and the errors were normal, but the afternoon saw her again working against time and the number of errors rose to 119. The rest of the week was normal.

Case V.—Another girl shewed similar effects. On a certain Tuesday, this girl had 20 errors in the morning and 22 in the early afternoon, after which trouble occurred with reference to her work and she was very much worried for the rest of the day ; at 5.30 her errors were 55, although by that time her work had

resumed normal conditions. On the next day, the errors in the morning were 21 and in the evening 26, the day after 21 in the morning and 30 in the evening.

It must be noted that if a girl was so rushed with her work that it would have worried her to come to do the " dotting," she was not tested, so I feel fairly sure that I was not measuring her distaste for leaving her work.

Case VI.—This case shews the effect of headache under normal conditions. The girl's morning range was 40 to 69, her afternoon range from 48 to 80. On a certain Tuesday her morning record was 48 and her afternoon 63; on the next day, she had a headache which, however, did not shew its effects in the morning, the errors being 52; but in the afternoon the errors rose to 114, a higher record than she had ever reached before, and on the following morning her errors were 84, followed however by 65 in the afternoon, by which time the headache was better. The rest of the week was normal.

Case VII.—This girl was a very regular worker and was regular in her " dotting." Her morning range was between 15 and 24 and the afternoon between 22 and 32 under normal conditions. However, on one particular occasion her afternoon record rose to 40, when she was suffering from a headache and a grievance, the former probably being the expression of the latter. I was unable to carry her records on, as the grievance resulted in her departure.

Case VIII.—This was a girl with a sore throat. Her morning range was from 48 to 65 and her afternoon range from 55 to 80 under normal conditions; as a result of slight illness her morning records (with one exception) remained within the normal range, but the evening records rose to 176. The one exception was a morning record of only 36, and this was after a sleepless night due to coughing. In another place * I have been able to shew that the immediate effect of considerable loss of sleep is a stimulating one. That, in the case of this girl, this result was not due to practice effect is, I think, shewn by the evening record, which was 176, and the fact that she never repeated it. The records returned gradually to the normal range.

Case IX.—This case is particularly interesting, as shewing the effect of standing all day, as against sitting half the day and standing half. The occupation of this girl, a sorter of heavy work, was fairly arduous, and during the period of the experiment the weather was very hot. She was a very energetic and accurate worker. For a fortnight, during which period she stood all day (nine hours), her usual morning records ranged between 42 and 64, and the afternoon records between 52 and 83. During the following week, her work was changed, so that she sorted

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* A Contribution to the Study of Fatigue. *Brit Journ Psych.*, 8, 3

part of the day and sat down to do marking for the rest of the day. The morning range for that week was from 17 to 38, and the afternoon range from 25 to 53. That this was not due to mere habituation is shown by some records later, which are affected by physical conditions *

Case X.—In the case of a folder, I was able to get a similar comparison, although not for so long, and her records were unfortunately complicated by the fact that at the time she was not in good health She was occasionally lent in emergencies to the marking department, where, as stated above, she could sit to work. When standing all day at the ordinary work of folding, she used to range between 44 and 88 in the afternoon. On the occasions when she sat down part of the day, her errors were between 20 and 28. It is only just to state that she had an internal trouble, so that sitting down was doubtless a greater relief to her than to the normal worker, but that consideration does not alter the fact that she benefited by the alteration of standing and sitting.

Case XI.—In the course of obtaining hourly dotting records, one of the subjects, a young ironer recently promoted to that work, gave such extraordinary variations as to challenge investigation. A comparison of the two days given in Table XIX. shows that the variations seemed to follow no principle whatever.

TABLE XIX.—*Diurnal variations in "dotting" errors. (A young ironer.)*

Day	Number of Errors								
	8 30	9 30	10 30	11 30	1 30	2 30	3 30.	4 30.	5 30
Tuesday ..	83	98	65	63	64	47	70	35	71
Wednesday	47	52	57	65	72	46	81	57	72

She was in good health and was familiar with the test, having done it morning and evening for five weeks prior to doing it every hour. In the course of conversation, I found out that her work varied from hour to hour and that she liked doing some things very much more than others. Some work, particularly handkerchiefs, she disliked intensely, other work such as lace and dainty things she liked. From what she said, I roughly graded her work into three classes, which I designated by the signs + + for her favourite work, — — for what she disliked, and + — for work towards which she had expressed little or no dislike. Table XX. gives her records.

* The department was at this stage reorganised as a result, so that the workers divided the two types of work

TABLE XX.—*Variations in "dotting" errors according to degree of interest in work. (The same girl.)*

Interest.	No. of Errors on Different Occasions.	Mean	Extremes.
+ +	47, 52, 58, 27, 36, 46, 36, 39, 36, 40, 47, 46	42 5	27–58
+ –	57, 64, 46, 57, 71, 72,	61·0	46–72
– –	65, 96, 75, 80, 77, 52, 68, 90, 67, 58, 87, 83, 98, 65, 63, 64, 70, 81, 72	74 5	52–98

With a few exceptions the work she disliked was monotonous ; the work she liked was that which repaid her labour by looking pretty when finished. As far as one could judge, during the monotonous period she sank into a state of acquiescence in existence and mental lethargy, which is reflected in the dotting by a characteristic inability to focus attention ; when her mind had been really occupied, she was mentally alert and better able to concentrate. These variations would effectually mask any fatigue which might have been present.

These individual studies are given to show that conditions of work and physical well-being actually have effects which can be measured. The dotting machine is a rather delicate indicator of physical and psychical changes, which in measuring output tend to be masked by the many variations in the work. But they are none the less having an effect, and although these studies are of individuals, these individuals can be taken as to a certain extent typical, there being no particular evidence to believe them all to be unique.

It is quite impossible to go into such detail with every case, but while those illustrating the particular point most clearly have been selected, yet there were very many others where on one or two days similar conditions were at work, and it is more than probable that they were present when the experimenter was merely observing output variations and so could not know the personal history of the worker so minutely.

3.—*Group Observations.*

Laundry A.—Records were obtained at Laundry A. from two groups of workers, namely, seven calender workers and seven girls engaged in packing and sorting. The records actually obtained extended over a period of five weeks ; but the averages given below represent a period of four weeks, as it seemed desirable to omit any week involving temporary disturbances, such as changes in physical well-being, personal troubles, excitement, etc. With so few subjects these temporary influences are liable to obscure the general factors. In order to minimise the purely individual differences in ability, the mean number of errors in

each girl has been taken as 100, and the correction made accordingly.

Table XXI.—*Diurnal variations in "dotting" errors for groups of different workers. (Laundry A.)*

Day of Week	Relative Number of Errors.			
	7 Calender Workers		7 Packers and Sorters.	
	Morning	Afternoon	Morning	Afternoon.
Monday . ..	100	116	87	115
Tuesday	86	90	93	114
Wednesday .. .	94	109	94	114
Thursday . ..	91	96	88	110
Friday	100	122	88	106
Mean	94	107	90	112
Percentage increase in afternoon	—	**13·8**	—	**24 4**

The period when these experiments were being done was one when there was not any rush of work, and the usual nine-hour day was being worked. In the case of the calender workers, there was very little variation from day to day, and a slight increase in the number of errors in the afternoon Friday was the day of the greatest number of errors. This work was fairly heavy muscularly and the girls stood all day. The other set of girls alternately sorted and packed. The work was less heavy muscularly, as the clothes were dry, but it is responsible, and the times of greatest pressure vary. The difference between the morning and afternoon periods was greater than in the case of the calender workers and was significant.

At this laundry only one hand ironer was available for the experiments. She was a middle-aged woman who offered to do the test. Her actual output records have been given above in a study of rest pauses and hand ironing. She was a piece-rate worker who rarely came in on Monday. Table XXII. gives her averages for three weeks.

Table XXII.—*Diurnal variations in "dotting" errors. (A hand ironer.)*

Day of Week	Number of Errors	
	Morning.	Afternoon.
Monday	—	—
Tuesday	82	105
Wednesday	66	85
Thursday	63	73
Friday	76	70
Mean	72	83
Percentage increase in afternoon	—	**15·0**

Laundry B.—Here it was possible to have the same test done on larger groups for periods of four weeks, the conditions and method of calculation being as described above. The results are given in Table XXIII.

TABLE XXIII.—*Diurnal variations in "dotting" errors for groups of different workers. (Laundry B.)*

Day of Week.	Number of Errors					
	15 Calender Girls		6 Packers and Sorters.		4 Ironers	
	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
Monday . .	94	100	102	116	96	115
Tuesday .. .	97	113	94	118	95	108
Wednesday .	96	101	91	105	91	102
Thursday ..	90	105	83	108	87	125
Friday	93	103	84	93	97	112
Mean ..	94	104	91	108	93	112
Percentage increase in afternoon ..	—	**10·6**	—	**18·7**	—	**20·4**

In each group there was an increase in the errors in the afternoon, although in no case was the increase very great, nor was it carried over to the following day. If one contrasts the slight variations with the effect of the variations in physical well-being, one realises that in so far as can be measured, the temporary physical derangements are of much greater importance.

4.—*Hourly and Daily Variations.*

It was possible to make hourly observations with this test on ten calender workers, five packers and four ironers, for a week. They had all been doing the test for several weeks twice a day, so there was no particular novelty about the new form.

In order to minimise the effect of individual variations in efficiency, the average of each girl has been taken to be 100 and the variations have been translated with these terms. Table XXIV. (which is based on 760 observations) shows the variations from hour to hour throughout the average day.

It will be noticed that the first hour of the morning is not so good as the succeeding one and that there is a general tendency for the errors to increase in number towards the end of the day; in the case of the packers (who at the time of these experiments were not very busy) the difference is too slight to be significant, but in the case of the calender workers it is definitely significant,* though not so great as in the case of illness.

* By "significant" is understood that the difference has been tested by mathematical methods and is likely to be greater than would occur by chance.

TABLE XXIV.—*Percentage hourly variations in "dotting" errors for groups of different workers.*

Hour	Number and occupation of workers		
	5 Packers	10 Calender workers	4 Hand ironers
8– 9 a m	103	94	107
9–10 ,,	90	92	94
10–11 ,,	95	95	99
11–12 ,,	93	102	98
12– 1 p m	—	—	—
1– 2 ,,	98	101	96
2– 3 ,,	103	99	98
3– 4 ,,	99	102	90
4– 5 ,,	111	109	106
5– 6 ,,	101	127	111

In Table XXV. the same data have been arranged, so as to show the variations on different days of the week.

TABLE XXV.—*Percentage daily variations in "dotting" errors for groups of different workers.*

Day of Week	Number and occupation of workers		
	5 Packers	10 Calender workers	4 Hand ironers
Monday	104	99	91
Tuesday	92	96	90
Wednesday	96	99	90
Thursday	106	108	112
Friday	106	103	114

The results show that Tuesday and Wednesday are the best days and that there is a general tendency to fall off on Thursday and Friday.*

VI. ATMOSPHERIC CONDITIONS IN LAUNDRIES.

1.—*Method employed.*

That the atmospheric condition of laundries is a matter of importance nobody will dispute, but what constitutes a good atmospheric condition is much more difficult to determine. Recent research by Dr. Leonard Hill† and others goes to show

* Cf. P. M ELTON (1921): A Study of Output in Silk Weaving (*Ind. Fat Res. Board, Report No 9*). LOVEDAY, J., & MUNRO, S H · (1920): Preliminary Notes on the Boot & Shoe Industry (*Ind Fat. Res Board, Report No 10*)

† HILL, L (1921) The Science of Ventilation and Open Air Treatment, Part I *Med Res. Counc Spec Rep No 32*.

not only that the physical rather than the chemical properties of the air are responsible for the general feeling of good health, but also that the thermometer (whether wet or dry bulb) fails to give a complete indication of the qualities of the air which affect the bodily comfort and efficiency of the workers. Thus the temperature of still and moving air may be the same, but the "*cooling power*" will be very different in the two cases. A person who on a hot day in summer may be unpleasantly warm, can gain relief by a ride on the top of an open tram or bus. In the same way the unpleasant effects of a moist tropical climate can be greatly reduced by artificially creating air movement.

The cooling power of the air is most conveniently determined by the kata-thermometer, a special form of thermometer so designed as to enable the time required for it to fall from 100° F. to 95° F. to be accurately taken. In order to eliminate the effect of variations in different instruments, from the time so required, the rate of cooling of the bulb per unit area per second is calculated by the use of a simple factor (the so-called "*kata factor*") depending on the size and shape of the bulb and marked on each instrument, and this in turn gives a direct indication of the cooling power of the surrounding air. The instrument can be used either as a dry or wet bulb thermometer, but in the present report all the readings relate to the dry kata. Instructions as to the use of the kata-thermometer are given in the Appendix (p. 56).

The cooling power of the air as measured by the dry kata (usually abbreviated into *dry kata cooling power*) depends upon :—

(*a*) The difference in temperature between the thermometer (which when in use is kept at approximately the temperature of the body) and the surrounding air.

(*b*) The rate of movement of air ("air velocity").

From many observations, Dr. Leonard Hill estimates that the dry kata cooling power should be about 6 for sedentary workers. Little of the work in laundries, however, can be considered sedentary and much of the work is fairly heavy. A cooling rate of 6·0 is, then, the very lowest that should appear in records of atmospheric conditions in laundries, a higher figure being desirable.

2.—*Results obtained.*

The following records were taken in 20 different laundries between February, 1921, and June, 1922 :—

Laundry I.—This was a single story building designed for the purposes of a laundry. Four positions were selected and hourly readings obtained for four days in December, 1921. The positions were :—

(*a*) Starching table.
(*b*) Receiving table of a calender.
(*c*) Hand ironing table.
(*d*) Table of a tandem press.

TABLE XXVI.—*Hourly variations in atmospheric conditions. Average of 4 days. (Laundry I.)*

Approximate Time	Outside		Starching Table			Calender			Hand Ironing			Presses.		
	Temperature °F.	D. K Cooling Power.	Temperature °F	D. K Cooling Power	Air Velocity (ft per min)	Temperature	D K Cooling Power	Air Velocity	Temperature	D. K Cooling Power	Air Velocity	Temperature	D. K Cooling Power.	Air Velocity
9—10	44 1	13 7	71 9	4 8	22	73 3	3 9	10	69 0	6 1	41	68 8	6·5	51
10—11	—	—	75 9	4 0	21	80 5	3 4	30	71 1	5 6	39	71 0	5 5	36
11—12	—	—	77 9	3 7	23	80 9	3 3	30	69 5	6 2	47	70 8	6 0	50
12—2	47 5	15 9	—	—	—	—	—	—	—	—	—	—	—	—
2—3	—	—	75 5	4 0	19	79 1	3 3	18	70 9	5 9	47	71 0	6 0	51
3—4	—	—	77 0	3 8	21	80 4	3 6	39	70 0	6 8	70	71 2	5 5	38
4—5	47 9	18 0	74 0	3 8	10	80 5	3 6	39	72 2	5 9	57	73 1	5 2	41

The results shew that even within an hour of beginning work, neither the region of the starching table nor that of the calender reaches the approved standard of 6 The other two places are approximately near this standard all day. It must, however, be noted that these records were taken in the winter, at a time when the outside temperature was low, averaging 47·5°F. at midday, also that the work carried on in these regions cannot be considered sedentary

This laundry was ventilated by a system by means of which fresh air is blown in through large air-pipes. The difficulty experienced in many laundries in large towns is that if a fairly high wind is blowing, dirt comes in with the air and spoils the work when wet. Hence one frequently finds a high temperature and stagnant atmosphere when the outside conditions are a fairly low temperature and high wind.

Laundry II.—This was also a single story building and of the latest design. Records were obtained between August 27th and September 23rd, and the table given represents an average of 20 days in all. The outside temperature was unusually high, averaging 72·2°F. at midday. The laundry was ventilated by fans as well as by doors and windows, which owing to the situation could be kept open practically all day in good weather.

It will be seen that in every position there was a consistent rise in temperature as the day went on, with, however, considerable variations from one part of the building to another. The hottest region, in spite of the fans in the vicinity, was that near the presses, of which there were three pairs. Reference to the table will shew that the range of temperature was from 73·9° F. at 8 a.m. to 93° F. at 5 p.m , and that of the cooling power was from 6·4 to 1·2. In order to mitigate these conditions, the lids of presses were protected with asbestos covers, and the pipes, not only of these machines but of all the others wherever possible, lagged. This was done in October, after a considerable fall in the outside temperature, so that a valid comparison could not be made.

TABLE XXVII.—*Hourly variations in atmospheric conditions.* (*Laundry II.*)

	Outside		Folding Table.			Collar Packing.			Calender.			Presses.			Ironing Table.			Sorting Room.		
Time	Temp	D K Cooling	Temp	D K Cooling.	Air Vel	Temp	D K Cooling	Air Vel.	Temp	D K Cooling	Air Vel.	Temp	D K. Cooling.	Air Vel	Temp	D K. Cooling.	Air Vel.	Temp	D K. Cooling	Air Vel.
9	64·1	11·7	67·0	8·6	113	—	—	—	71·8	5·0	27	73 9	6·4	99	—	—	—	—	—	—
10	—	—	66·0	8·2	85	70·0	5·4	33	73·0	4·6	22	77·0	5·2	77	73·0	5·8	61	—	—	—
11	—	—	77·5	5·3	90	—	—	—	70·0	5·4	24	81·3	4·7	122	77·5	5·1	72	—	—	—
12	72·2	7·5	—	—	—	83·5	3 3	58	73·5	4·5	22	83·6	3·6	82	76·0	5·1	61	70·8	6·6	71
1	—	—	—	—	—	—	—	—	69·0	6·4	50	82·0	4·3	105	—	—	—	—	—	—
2	—	—	—	—	—	86·0	2·5	42	—	—	—	80·5	4·3	76	83·0	3·4	57	—	—	—
3	—	—	76·7	5·1	68	79·7	3 5	28	79·3	3·3	19	87·2	3·2	145	82·0	3·4	44	74·0	5·7	66
4	—	—	76·3	5·1	64	82·5	3 5	39	83·0	2·7	21	86·6	2·5	52	84·9	2·4	24	77·8	4·3	44
5	—	—	—	—	—	85·0	2·5	30	80·0	2·6	8	88·6	1·4	8	79·5	3·6	30	—	—	—
6	69·8	9·0	79·5	4·3	63	—	—	—	78·0	3·9	47	93·0	1·4	83	82·0	4·2	98	—	—	—

TABLE XXVIII.—*Hourly variations in atmospheric conditions during the day (Laundry III.)*

Approximate Time	Calender (1). Temperature	Calender (1). D.K. Cooling Power	Calender (1). Air Velocity ft per min	Calender (2). Temperature	Calender (2). D.K. Cooling Power	Calender (2). Air Velocity ft per min	Hand-Ironing Table. Temperature	Hand-Ironing Table. D.K. Cooling Power.	Hand-Ironing Table. Air Velocity ft per min	Packing. Temperature	Packing. D.K. Cooling Power.	Packing. Air Velocity ft per min	Outside. Temperature	Outside. D.K. Cooling Power.	Outside. Air Velocity ft per min
(a) Average of two Cool Days, May 1922															
9.30–10.30	72·0	8·6	195	73·5	5·0	34	69·0	8·6	142	67·5	6·1	32	54·0	23·1	581
10.30–11.30	71·5	10·1	276	73·5	5·1	38	70·5	7·6	113	68·3	6·1	36	—	—	—
11.30–12.30	73·5	8·7	230	78·0	4·6	59	71·0	7·2	100	69·5	5·7	34	—	—	—
1.30–2.30	75·5	7·8	215	76·0	4·7	47	73·0	6·8	112	70·5	5·8	44	56·8	19·8	473
2.30–3.30	75·5	7·3	186	78·0	4·7	73	74·0	7·2	141	70·0	5·7	35	—	—	—
3.30–4.30	76·3	7·2	190	77·5	4·1	34	74·0	6·9	127	72·0	5·5	43	61·5	19·6	615
(b) Hot Day in June 1922															
9.30–10.30	93·5	2·0	461	83·5	3·7	88	—	—	—	82·0	2·9	22	74·0	8·4	222
10.30–11.30	90·5	2·8	280	—	—	—	92·0	2·2	271	85·0	2·2	16	—	—	—
11.30–12.30	93·5	1·9	396	85·0	2·5	28	93·0	1·4	141	89·0	2·1	66	—	—	—
1.30–2.30	98·0	*	*	87·0	1·6	8	95·0	*	*	91·0	1·06	10	81·0	6·0	230
2.30–3.30	—	—	—	88·0	1·75	19	98·0	*	*	91·0	1·3	28	—	—	—
3.30–4.30	95·0	*	*	85·5	2·1	16	97·0	*	*	92·5	0·86	39	78·0	8·7	375

* In these positions the temperature of the region was too high to enable cooling power and air velocity to be estimated. (See Appendix, p. 56.)

Laundry III. was a one-storied building designed for a laundry and divided into two parts. The main building was ventilated by three impelling fans on the north side, set at about head level, and three expelling fans on the south side, thus drawing cool air in on one side and expelling it on the other. There was also a large exhaust fan in one gable as well as open windows and doors. Records were taken on two cool days in May and one very hot day in June 1922. The four positions chosen were :—

(*a*) Calender (1) between two impelling fans
(*b*) Hand-ironing tables
(*c*) Packing tables
} in main portion of building.
(*d*) Calender (2) in wash-house, near window and door.

It will be seen from Table XXVIII. that in cool weather, with an outside midday temperature averaging 56·8° F., the cooling power of the air in the main building never fell below 5·5, and was generally above 7·0. The region of Calender (1) shewed an average of 7·1, which is particularly good, considering the heat of the rollers. At Calender (2), where there were no fans, the average D.K. cooling power was 4·7.

With an outside temperature of 81°F. at midday, the results were very different. In spite of the fans, the cooling power never rose above 2·9 in the large room and only in the second hour of work, while Calender (2) was in the coolest place. This was probably because the roof of the main building had a large southern tiled slope, which became very hot in the sun, while the smaller portion only presented its gable to the south.

Laundry IV.—This was a well-ventilated one story building of an up-to-date pattern. There were two large exhaust fans in the gables as well as many windows and doors.

The average of records taken on two days in May, 1922, the outside temperature at midday being 64°F., is given The positions chosen for readings were :—

(*a*) Ironing table.
(*b*) Calender near open door.
(*c*) Packing room
(*d*) In region of gas-heated ironing machines.

TABLE XXIX.—*Hourly variations in atmospheric conditions.* (*Laundry IV.*)

Time.	Outside		Ironing Table			Calender			Packing			Ironing Machines		
	Temperature °F	D K Cooling.	Temperature °F	D.K Cooling	Air Velocity	Temperature °F	D K Cooling	Air Velocity	Temperature °F	D K Cooling	Air Velocity	Temperature °F	D K Cooling	Air Velocity.
9.30	54·5	13·6	66·5	6·4	42	73·0	5·3	41	67·5	5·6	21	74·0	5·5	56
10.30	—	—	68·0	6·2	38	72·0	5·6	41	68·0	5·9	32	73·0	7·5	141
11.30	—	—	69·5	5·8	36	72·0	5·4	41	69·8	6·0	40	74·3	6·2	91
1.30	64·0	12·6	71·0	6·4	65	76·0	4·2	28	72·5	4·6	19	76·3	5·9	119
2.30	—	—	73·0	6·1	69	78·0	4·3	41	73·3	4·5	21	77·8	5·0	80
3.30-4.30	63·0	15·7	72·0	6·2	64	78·3	4·5	57	73·8	4·8	32	78·5	5·6	129

The ironing room approximated to 6·0 all day, and the region of the ironing machines maintained a fairly high average. The lowest cooling power recorded was 4·2 at the calender during the hottest part of the day, where, however, there was never a reading above 5·6, the average being 4·7 for the two days.

Laundry V.—This was a single story building adapted for a laundry. It was very crowded and not well ventilated, and being situated in the town, in a row of undetached houses, had no windows at the sides

TABLE XXX.—*Hourly variations in atmospheric conditions. Average of two days' records. (Laundry V.)*

Approximate Time	Outside		Ironing Table			Packing Table			Calender Room			Collar Room.		
	Temperature °F	D K Cooling	Temperature °F	D K Cooling	Air Velocity. Ft per mt	Temperature °F	D K Cooling	Air Velocity Ft per mt	Temperature °F	D K Cooling	Air Velocity Ft per mt	Temperature °F	D K. Cooling.	Air Velocity Ft. per mt.
10–11	68·5	7·4	84·5	2·7	35	71·5	6·8	88	95·0	*	Could not be calculated	85·0	2·4	25
11–12	—	—	86·5	2·0	19	76·5	5·0	61	95·0	*		—	—	—
12–1	—	—	88·0	1·6	12	78·5	3·8	32	—			87·5	1·4	<8
	77·0	6·9	—	—	—	—	—	—	—			—	—	—
2–3	—	—	88·3	1·5	10	80·0	3·5	27	98·5	—		88·0	1·4	<8
3–4	—	—	90·0	·9	< †	82·0	3·5	46	98·0	—		—	—	—
4–5	77·3	5·4	89·5	1·0	<8	82·0	3·6	48	102			90·5	·6	<8

* *See* footnote to Table XXVIII
† <8 means less than 8, etc

The cooling power here was extremely low. The packing table, which was near the entrance where there was a large open door, was the only place where the cooling power was above 3·0. The lowest temperature recorded was 71·5° at 10 a.m., and the highest 102°F. at 4 p m.

Less detailed records were obtained in fifteen other laundries, for one or two days in each. In every laundry records were taken in the region of the ironing tables and in that of the calenders, and in some cases readings were also taken in the packing room. The table given shows the diurnal variations in temperature, D.K. cooling power and air velocity in these fifteen laundries, arranged in order according to the outside temperature at noon (12 p.m. winter, 1 p.m. summer-time) on the day when the records were obtained. Laundries I., II., III., IV. and V. are included in the table in their proper places, making the total number of laundries where records were obtained, twenty. Laundries II. and III. are shewn twice as records were taken with widely divergent outside temperatures.

TABLE XXXI.—*Diurnal variations in temperature, cooling power, and air velocity in 20 laundries, arranged in order outside of midday temperature*

Laundry.	Formerly.	Mid-day. Outside.		Hand Ironing Tables.			Calenders.			Packing Tables.		
		Temperature °F	D.K Cooling power	Temperature °F	D K Cooling power	Air Velocity ft per min	Temperature °F	D K Cooling power	Air Velocity ft per min	Temperature °F	D K Cooling power	Air Velocity. ft per min
1	—	87·0	3·3	85—95	2·5—·0	28—	95—107	—*	—†	78—89	4·4—1·5	47—12
2	—	81·0	5·9	81—90	3·7—·8	43—8	91—96	1·7—·0	82—	77—89	4·7—1·7	82—12
3	III	81·0	6·0	92—97	2·2—·0	271—	84—98	3·7—·0	450—	82—93	2·9—·9	66—10
4	—	79·0	6·4	84—93	3·3—1·2	56—16	87—95	2·4—·0	52—	80—87	4·2—2·3	66—43
5	V	77·0	6·9	85—92	2·7—·5	35—under 8	95—102	—*	—‡	72—84	6·8—3·0	88—32
6	—	74·0	8·8	76—84	4·4—2·7	32—22	78—88	4·2—1·3	141—under 8	70—82	5·2—3·1	39—25
7	II	72·2	—	73—85	5·8—2·4	72—24	74—93	6·4—2·6	50—8	71—78	6·6—4·3	71—44
8	—	71·6	—	81—87	3·1—2·1	24—21	82—85	3·8—3·0	88—44	—	—	—
9	—	67·8	—	77—80	4·8—3·8	58—33	85—92	5·4—2·2	410—317	—	—	—
10	—	66·0	9·7	76—79	5·0—3·7	52—19	85—88	4·2—3·1	172—94	68—70	7·3—6·3	94—52
11	—	65·0	—	79—82	4·4—3·3	83—23	80—82	3·3—3·0	30—14	—	—	—
12	IV.	64·0	12·6	64—74	7·1—5·6	82—12	71—79	6·2—4·1	66—22	67—74	6·8—4·4	52—19
13	—	63·0	—	78—81	4·7—4·0	68—55	84—93	3·3—1·5	77—41	—	—	—
14	—	61·5	12·4	77—84	3·3—2·6	52—under 8	66—92	7·8—·0	113—under 8	70—77	6·2—4·1	61—25
15	—	61·0	—	78—79	4·1—1·6	38—18	82—87	3·8—2·2	105—26	—	—	—
16	—	59·0	—	70—77	6·4—4·2	52—33	73—86	4·8—2·9	81—28	—	—	—
17	—	58·0	—	74—76	7·2—5·5	143—57	85—87	4·3—1·8	197—11	—	—	—
18	—	58·0	—	70—74	4·8—4·5	25—16	70—74	5·2—4·3	41—20	—	—	—
19	III	57·0	19·8	69—74	8·6—6·8	143—100	72—79	10·1—4·1	276—34	68—72	6·1—5·5	44—32
20	II	56·5	—	72—76	6·0—4·6	70—35	—	—	—	69—76	7·5—4·8	84—41
21	—	55·6	—	74—81	5·5—3·2	62—24	76—81	4·3—3·4	34—24	—	—	—
22	I	47·5	15·9	69—72	6·8—5·6	70—39	73—81	3·9—3·3	39—10	—	—	—

* *See* footnote to Table XXVIII

Note.—The wide variations in temperature and cooling power shown near the calenders in laundries 7, 14, 19, are due to the fact that in these laundries readings were taken at two very differently situated calenders.

Table XXXI shews that of the fourteen laundries where records were obtained with outside temperatures, lying between 47·5 and 67·8° F., in only four was the desired standard of 6 approximated all day at the ironing tables, and in none was the standard maintained near calenders.

In hotter weather, with outside temperatures between 71·6 and 87 at midday, only one of the eight laundries tested had a region where the cooling power remained above 4 all day, *i.e.*, the packing room of Laundry III., where there was no hot machinery. The ironing tables did not give a higher reading than 5·8, and there was only one calender reading above 5.

Of the 55 regions shown in Table XXXI (*i.e.*, 22 ironing, 21 calender, and 12 packing regions), 3·6 per cent. maintained the standard of 6 all day, 31 per cent. reached it at some time during the day, generally in the early morning, and 69 per cent. never reached it at all.

3.—*Comparison of Laundries with other places.*

Table XXXII gives the percentage frequency of the D.K. cooling power and air velocities observed, shown in comparison with those of the pottery, boot and shoe, and cotton industries. Records from the ironing, calender and packing departments only were used, and each laundry is only represented once (where more than one day's records were obtained an average was made).

TABLE XXXII.—*Comparative records of laundries, potters' shops, boot and shoe factories, and cotton-weaving sheds.* (*Readings taken with outside temperature of* 50° *F. or more.*)

A.—Dry Kata Cooling Powers.

D K Cooling Power.	Percentage Frequencies.							
	1 Laundries		2 Potters' Shops		3. Boot and Shoe Factories †		4 Cotton-Weaving Sheds ‡	
Below 2·0	19	88% below 6 0	0	89% below 6 0	0	37% below 6·0	·1	100% below 6·0
2—2 9	17		6		0			
3—3·9	**21**		23		8		·31	
4—4·9	19		**34**		10		**52**	
5—5 9	12		26		19		16	
6—6 9	7		8		**28**		0	
7—7·9	4		2		20		0	
8—8 9	·7		1		9		0	
9 or more	·3		0		6		0	
Total Observations	300		463		276		163	

* VERNON, H M (1922)·—Two Investigations in Potters' Shops *Ind Fat Res. Bd Report No 18*

† HAMBLY, W. D & BEDFORD, T (1920) —Preliminary Notes on Atmospheric Conditions in Boot Factories *Ind Fat. Res Bd Report No 11*

‡ WYATT, S (1922):—Atmospheric Conditions in Cotton Weaving Sheds *Ind. Fat Res Bd Report No 22.*

B.—Air Velocity (feet per minute).

Air Velocity in Feet per minute.	Percentage Frequencies.			
	1 Laundries	2 Potters' Shops	3 Boot and Shoe Shops.	4 Cotton-Weaving Sheds
Under 10	6 } 21%	4 } 62%	— } 18%	Full data not available.
10—14	3	13	—	
15—19	6	**24**	—	
20—24	6	21	—	
25—30	12	16	15	
31—35	10	7	13	
36—40	7	6	14	
41—51	11	3	**20**	
52—74	**22**	5	10	
75 or more	17	1	10	
Total Observations ..	283	463	273	—

It will be seen that in the laundry trade, 88 per cent. of the D.K. cooling power records were found to be below 6·0, as against 100% in cotton-weaving sheds, 89 per cent. in potters' shops, and 37 per cent. in boot and shoe factories; but in laundries 36 per cent. were below 3·0, as against 6 per cent. in potters' shops, 1 per cent. in cotton-weaving sheds, and 0 per cent. in boot and shoe factories. The air of laundries, as a whole, may be said, therefore, to have a lower cooling power than any of the other industries.

The velocity of the air in laundries is considerably higher than that of the boot and shoe factories and a great deal higher than that of the potters' shops, where the maximum frequency falls between 15 to 19 ft. per min., as against 52 to 74 ft. per min. in the laundries. An exact comparison with cotton-weaving sheds cannot be made, but here also the air velocity in laundries seems to be the higher, since the average air velocity in cotton-weaving sheds is estimated at 24·5 ft. per min.

Although a more extensive investigation would probably reveal further differences in particular laundries, the twenty laundries represented in the foregoing tables are fairly typical and very varied in type, since they include laundries built for the purpose and several in various degrees of conversion. None of them would be classified as really bad and the greater number are fairly good.

Of these laundries none maintained the minimum standard of 6 throughout the building all day, and in only four was 6 approximated in any one department throughout the day. The temperatures ranged from 64° F. in the early morning to 107° F. later in the day. In only seven instances a temperature below 70° F. was recorded. 88 per cent. of the cooling powers measured were below 6·0.

It is difficult to see how a calender department could be kept cool, but there are obviously considerable individual differences, e.g., contrast Nos. 5 and 6 in Table XXXI. With an outside temperature differing by three degrees F., the temperature in the calender rooms varied between 95 and 102° F., and 78 to 88° F., respectively. In No. 5 there was no cooling power in the air all day and in No. 9 the cooling power varied between 6·4 and 2·6. Nos. 12 and 19 (Table 3), which were the best recorded, were large airy buildings with their calenders placed near open doors or between impelling fans. In Nos. 5 and 1 the calenders were close together in a very badly ventilated portion of the building. Nor was over-heating only due to the number of stories, for both 13 and 18 were two storied buildings, while 6 and 7 were single storied.

From the point of view of the amount of air space for each worker, it is practically impossible to overcrowd a laundry, because the size of the machines is so great compared with the number of people who work them; but when machines which, from the nature of their work, must be at a very high temperature, are placed in an ill-ventilated room, which may have been made by converting several rooms of an ordinary dwelling house into one, it is to be expected that the air will become overheated and hence have a very low cooling power.

The hand ironing department is, in most laundries, a more comfortable place, although the cooling power of the air is still not high enough. The temperatures recorded were between 64° to 97° F., as against 66° to 107° F. in the calender rooms. Nearly every laundry uses gas irons (although heating by means of a stove is not unknown).

The packing room is more comfortable again, since there is no machinery. Here the temperature in the cases where records were obtained lay between 67° to 93° F., but even here, in only one laundry, No. 10 (Table XXXI), was a cooling power of 6 maintained all day.

With these facts before us, it seems fair to say that the tendency in laundries is for the cooling power of the air to be inadequate, so that the insistent problem for most laundries is to reduce the temperature in regions dominated by calenders and presses ; even where a high temperature is necessary, the conditions can be improved by keeping the air moving.

When the atmospheric temperature reaches a high level, the body has to be cooled entirely by sweating. Adequate movement of the air by fans * is then required to maintain cooling by evaporation of sweat at a proper level. It must be borne in mind that these high temperatures throw a strain upon the heart, which has to send blood to the skin to be cooled by sweating, and so enhance the onset of fatigue.

*The use of small fans, which merely keep the air in motion and can easily be fixed without structural alterations has proved beneficial in several places.

VII. THE HEALTH OF LAUNDRY WORKERS.

Of all the occupations open to women, of the class which cannot be specifically described as dangerous, none is, in the public press and ordinary conversation, so frequently stigmatised as unhealthy as the laundry trade. The average speaker using the word laundry usually has in mind the general atmosphere of the cellar or kitchen of a dwelling-house when the domestic washing is in progress. That buildings exist which have been designed for the task of washing, drying, and ironing clothes, and that in such buildings the steamy atmosphere conjured up in mind by the thought of washing need never exist, is not recognised. It is true that there are bad buildings, from which steam cannot escape readily, but a whole industry cannot with justice be condemned for the inadequacies of some members.

Again, a large number of laundry workers have been in the trade for many years, and have lived through the old days when the hours were very long and wages very low, so that in their own persons they bear the marks of the strain of such an existence. Of recent years, however, the united efforts of Factory Inspectors and of the more enlightened proprietors and directors, have resulted in such marked improvement that to say that a building is used as a laundry signifies nothing except the washing process; conditions may be indifferent, they may be almost ideal. It is certainly true to say that the industry as a whole is ceasing to be despised, and is now both respected and self-respecting.

To obtain definite evidence as to the health of laundry workers has proved more difficult than was at first anticipated. Laundry work is essentially a married woman's occupation, and hence much that is vaguely termed sickness is due to natural causes. The insurance records proved inadequate owing to the lack of differentiation of laundry workers. In order to obtain some information on the subject, with the co-operation of the Secretary of the Launderers' Federation, members were asked to fill up regularly forms giving details of the time lost by their workers each week and to state the alleged reason. A large number of replies was received, but only a limited number could be used for statistical purposes, as the length of time during which the forms were filled up varied. These notes are based on returns made by 23 firms for three winter and three summer months; they relate to 1,144 women workers, of whom 274 were married women. The alleged reasons for absence are those given by the worker, and only partly represent a medical opinion, but for practical purposes they are not valueless. If some specific occupational disease existed, the probability is that any illness resembling it in any particular would be classed as such. The chief complaints given in these returns are colds and influenza, headaches and biliousness (under which name probably lies disguised various disturbances due to the menstrual period), anæmia, accidents, all of them complaints which are not exclusive

to the laundry worker Many firms state that their workers do not stay away to any great extent, and that for this reason they do not keep records. Table XXXIII. gives a summary of the data collected.

TABLE XXXIII.—*Percentage of time lost owing to (a) illness and (b) other causes compared with total possible working hours.*

Class of Worker.	Time Lost (Percentage of Total Possible Hours)			
	Winter		Summer	
	Illness	Other Causes	Illness.	Other Causes.
Married Women	1 2	0 9	1 5	1·0
Single Women—				
Over 16	1·8	0·4	1·4	1·3
Under 16	1·5	0 2	1 0	0·3

While these figures cannot be taken as more than a rough sample of the whole, yet as the firms from which the data for these figures were received represent most types of laundry building, and are situated in widely differing parts of the country, it seems reasonable to assume that they are fairly representative of the trade.

Given good conditions there seems to be no reason to look upon the trade as detrimental to the health of the workers. The fluctuations of health due to specific conditions, such as too much standing, faulty movements, inadequately adapted machinery, have been discussed in a previous part of the Report.

VIII —GENERAL CONSIDERATIONS.

The studies here reported are but tentative and are offered rather as indicating the direction in which future research ought to go, than as final conclusions. The field is too wide, and the state of our present knowledge too limited, for far-reaching generalisations to be drawn, but we feel justified in pointing out some of the factors which affect the work of the laundry workers.

1.—*Organisation.*

The methods of organisation still existent in many laundries are those left over from totally different industrial conditions. Once human labour was cheap and could be worked very long hours, hence no particular thought was necessary, and it is obvious that it was not given. Many laundries started as hand laundries in a small house, and machinery was gradually added as business developed, more rooms being annexed to meet this development. The result is that machines have had to be placed where they fitted into the already existent scheme of things, and not where

they naturally belonged in relation to the previous and successive process. Hence, if the path taken by any one article in its progress through the laundry were drawn, it would be seen at once to be devious, and as a corollary that much wasted effort was entailed. Either expert workers employ their time in running about to get their work, or young beginners spend their time waiting on expert workers ; in both cases there is an unnecessary expenditure of energy engendering fatigue. Mentally, too, there is the constant irritation involved in the interruption of the work at irregular intervals.

Again, unnecessary irritation is frequently caused by defective organisation within particular processes. At some laundries collar work does not run smoothly, so that the girls at one stage are either behind or ahead of the rest. The result is much argument and in some cases vituperation, with its attendant interference with everyone's work. Thus some girls are working against time in order to get work ready for the next process, while others are dawdling. As some girls are easily upset when having to increase their speed it is more than probable that the work will suffer. (*See* dotting records p. 29.)

2.—*Supervision.*

Another factor which influences the attitude of mind towards the work, and hence the work, is the type of person in authority. Forewomen, supervisors or manageresses, are not infrequently chosen for an ability to do well themselves the class of work they are to supervise, a method of selection which certainly has some merits, but some drawbacks ; if that person in authority has an irritating manner, and a capacity of rubbing subordinates up the wrong way, then there will be constant irritation with its attendant effect on the work. A person who is to be in charge of others must have the sympathy to understand others, and the power to rouse in the subordinate a desire to work well. Then the work goes on just as well, even though no one is at the moment watching, and is limited only by the ability of the worker, not by a mental attitude of unwillingness. The effect of one human being on another is very great and the person in authority whose vitality can inspire others is vastly to be preferred to the depressing person whose mere presence casts a gloom. It is obviously impossible to get scientific statistics of such differences, but that they are very real cannot be doubted by the unbiassed person who spends much time in different factories and departments of factories.

It has been the lot of the writer to be in different departments of laundries, when an unexpected rush of work has necessitated overtime. Contrast the difference in attitude in the case where the workers are saying, " If they'd only manage things properly in the place it wouldn't be necessary " and a general depression prevails, with, " Well, I'm sorry, but of course we can't let Miss X. down ; we'll soon get it done." It must be remembered that the extra money does not always appeal with irresistible

force to all workers when overtime is the question. Any laundry is liable to have a sudden increase of work in a particular week, which amount may not occur again for many weeks, so either overtime must on these occasions be worked, or the normal number of workers must be in excess of the normal demand, or extra workers must be brought in temporarily; the second alternative is financially impossible even if it were desirable, while the third is bad from several points of view, which being so there remains only the first.

3.—*Rest Pauses.*

A frequent objection given to allowing definite rest pauses is that already many involuntary rest pauses occur in the nature of the work; it would probably, however, be found much more satisfactory if the work were so organised as to minimise the casual rests and arrange for definite rests at definite times.

4.—*Change of Occupation.*

Where a process involves a rather stereotyped limited movement frequently repeated, such as, the back-bending when goods are sorted from the floor, the best relief would be to work on a process which brings into action other muscles. Contrast the effect of folding sheets or table cloths with the bending involved in sorting all day (as is often done), or with the frequently repeated movement of the press. The former calls into action many muscles, allows for chest expansion and is graceful and rhythmic

5.—*Provision of Seats.*

Even in the best regulated firms the nature of the work sometimes involves a stoppage in a particular department which may last a long or short time, *e.g.*, a foggy day with its attendant necessity for re-washing, may involve a complete department in a period of no work. When this occurs, why not allow the workers to sit? There seems to be a belief in the minds of many managers (I use the word as common gender) that some peculiar merit exists in the upright posture; if a worker is standing she must be working, if sitting then she is wasting time Physiologically, the argument is wholly unsound. Any one position maintained for a considerable time is tiring, the sitting no less than the upright, and to allow a change of position is to bring into play other muscles and hence give relief. While a worker is sitting, if her work is usually done standing, she is becoming more, not less, fit for more work.

There are certainly not a few operations in a laundry which can be performed while the worker is sitting, *e.g.*:—

(*a*) the preparing of collars for the collar-steaming machine does not require a standing position, and where, as is frequently the case, the worker of the collar steaming machine also prepares the collars for placing on the machine, she could quite advantageously alternate her position with good results. This is done in some of the best laundries;

(*b*) the taking off from the calender of small articles, such as table napkins and handkerchiefs, where several girls are engaged on the same machine, so that a constant change of place along the machine is not necessary. A small bench which can be put aside when sitting is impracticable is all that is required, and this is actually done in some laundries, but in very few ;

(*c*) the marking of articles in cases where they are marked by hand by girls who are not actually sorting as well. In the latter case markers and sorters might alternate so that no one girl necessarily stood up all day

In fact one very great reform which laundries could easily make would be to organise as many processes as possible to permit of occasional sitting. Many a time has a worker been heard to remark at the end of a day " I'm not tired, but my feet ache so " It is a rather prevalent view among launderers that this does not matter, or that the worker is making an unnecessary fuss. But any discomfort matters ; while there is any pain, whether real or imaginary, which is sufficiently obtrusive to force itself into consciousness, then there is divided attention, which means that the work and the pain are competing in the worker's consciousness, a state of affairs which is unprofitable for the work.*

When, to the standing for nine hours a day, is added that the standing is done quite often on a concrete floor, it is small wonder that feet ache. It is much more comfortable to stand on a wooden floor, and workers who have tried both are quite clear which they prefer. Where the floor is not made of wood, wooden stands could quite easily be laid down in most departments to stand on, and would be very much appreciated.

6.—*Shoes*.

Many workers have told me that they do not feel particularly tired at the end of an ordinary day, but that their feet ache. In some cases it is obvious that one contributory factor lies in the faulty foot-gear. The perfect shoe for prolonged standing is not a cheap one and in fact it probably has not been designed, but it clearly cannot be one with narrow toes and too high heels, and yet many girls systematically wear such a type. Equally wrong are the very soft, or very old shoes, beloved of the elderly hand ironers ; for here there is no adequate support. In an excellent laundry in the north of England, employing a very good type of worker, the girls themselves told me that the very best shoe for standing purposes was the clog. Most of them changed from their outdoor shoes, which were of a fashionable type, into clogs for working. In many cases one cannot help feeling that the workers are definitely suffering from flat foot and that the only help must come from an expert medical adviser. Even if it is too late in the case of the elderly workers, much might be done to prevent the young girls suffering likewise.

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* The provision of seats for occasional use is now compulsory under the Laundries (Welfare) Order.

7.—*Adaptation of Machines, etc.*

Much more, too, might be done to adapt the machine to the worker instead of adapting the worker to the machine. Machines are necessarily of standard size, but one cannot, therefore, assume that workers will also conform to the standard size. One firm at least has gone to considerable trouble to adapt the size and position of the "feeding table" for calenders to the height of the workers, but where this is impracticable more could be done by the use of suitable stands. Particularly does this apply to hand ironing, for which the worker always stands. The workers change, the tables remain; and so generations of workers adapt themselves with astonishing docility to the tables.* But it will be found that there are great individual variations in length of arm, relative length of body and leg, as well as in height, so that close observation of a group of workers who have been engaged in hand ironing for many years will reveal the adaptations their bodies have had to make, the round shoulders, forward drop in necks, and flat feet The designing of a suitable seat for hand ironers to work at for part of the day is a problem awaiting solution.

Another machine which has received far too little attention from the point of view of good physical attitude is the press used for ironing soft parts of many articles and particularly such things as workmen's overalls, aprons, coats, etc. (*See* Plate IV., opp. p 14.) This machine is a relatively new addition to laundry machinery and has a very nicely adjusted arrangement whereby the worker brings down the lid with an arm movement, while at the same time she presses a treadle with her foot which assists in the arm movement and locks the lid. Now if the machine is in good working order and well balanced this action is quite easy and involves no great expenditure of muscular effort, but, unfortunately, the engineers of many firms have failed to realise the necessity for careful attention to this, so that it is not uncommon to find a girl having to put far too much effort into the movement and performing a few jumping steps on a treadle before the lid is closed. But even with a well-balanced machine the worker through ignorance is often at fault and brings down the lid with an entirely unnecessary effort using the treadle just a little too late for her to get its assistance at the right time. I have heard workers complain that the machine "shook their insides," an effect quite unnecessary from the mechanical point of view, and wholly dangerous from the physiological.

The general remarks apply both to the single and the tandem press; in the case of the latter, however, the presses are arranged at right angles to one another, and the one worker can manipulate two, for by working the lid of one press, she automatically releases the other lid, which then flies up leaving the table free for fixing or arranging another article or another part of the same article; having satisfactorily placed this, the worker then pulls down the

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* The Influence Our Surroundings Exert On Us, by Sir W Arbuthnot Lane.

lid, at the same time pressing the treadle of the second press, which releases the first lid and locks the second, and so on. Now for some reason, nearly every girl I have watched using this type of machine uses the same foot for both treadles, involving a very awkward bodily movement, causing too great pressure to be exerted on one foot, and in a few extreme cases of young girls tending to make one shoulder higher than the other, in addition to another effect, which often appeals to the worker more than these physical considerations, wearing out one shoe much more than the other. If the two feet are used alternately the whole movement becomes more graceful and natural. It takes some time to alter a well-fixed habit, and workers habituated to the one foot movement have to be watched very carefully when attempts are being made to alter their action ; if, however, more attention were paid to the teaching of beginners, a bad habit need never be formed. As this movement, which involves an upward movement, may be performed about 200 times an hour, it is easy to see that in time the cumulative effects of a bad habit are likely to be serious.*

This machine, owing to the varied nature of the work done is very difficult to study numerically, but from prolonged observations of its use in many laundries it seems to the writer that it is one for which more workers might be trained so that no one worker—particularly a growing girl—needs to work it for a whole day at once. Some few workers seem to be attached to it, but in my experience it is not a popular machine. One reason alleged is that it is unpopular as tending to minimise hand ironing. This may at one time have been the stated reason, but it implies too great faith in the reasoning powers of young people to believe that to be the only reason.

It is true that the movements become mechanical, but actually the work is more varied than calender work which is generally popular. The same arm and foot movement is performed more frequently than the calender movement on the whole, but this is not true when small articles are being put through a calender. The movement is certainly heavier from the muscular point of view than the calender work, even with the best balanced machine. The psychological point of view ought, however, to be considered. Calender work is team work ; the group of girls generally occupied on the particular machine know one another well, and work with one another ; it is possible to be fairly sociable on calender work. The hand ironers, too, generally form a definite group, though the work is individual. But the girl working a press is rather isolated ; many laundries possess only one press, which is frequently placed rather far from the other workers. One worker told me that she disliked the press because she had far too much chance to think about herself, whereas on hand ironing the work itself

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* From this point of view these presses are capable of considerable improvement, and as they are relatively new machines, it has been suggested that they should be so designed as to facilitate the use of both feet alternately.

demanded more attention, and also she could talk occasionally to others. The remedy is to train more girls to use it and let them work a fewer number of hours at it.

The height of iron stands is also worthy of consideration. The lifting up and down of an iron is unproductive labour: to have an iron stand which is six inches high involves the worker in the extra and unprofitable task of lifting a weight up to a given height and down again. As the operation may take place about 60 times an hour, the accumulation of waste effort is great in a day. A stand which only necessitates a sliding movement is much more satisfactory.

Many of the processes in laundries involve the loss of only a few seconds, but it must be noted that those seconds accumulate. Suppose only one second an hour is lost for each of 150 workers, then in a week over two hours are lost; actually the losses in seconds, and accordingly in the weekly accumulation of waste time, are much greater. The suggestion is not that a system of watching be instituted so that a worker feels driven (for that in itself is waste), but that the unnecessary waste should be checked and work allowed to progress smoothly, a condition much more satisfactory to the worker and the work.

8.—*Fatigue.*

It must be remembered that the fact that there is little or no depreciation or diminution of output at the end of a working day is no proof that fatigue is absent. It might well be that a certain habitual standard is maintained but at greater effort to the worker, and of this there is at present no standardised measure. A point which cannot be brought out in these figures is that when occasion permits, a certain element of selection takes place, so that easier articles are chosen. This can obviously only refer to such processes as hand ironing. The particular ironer whose records have been given above, always tried to avoid doing shirts belonging to fussy customers during the last period, on the grounds that she did not feel equal to the anxiety. Another worker who did shirt-front polishing by hand, said she preferred not to do it during the last period of the day, as she felt it too great an effort. I think that we may safely look upon these as fatigue effects, and that further prolongation of the day would result either in diminished output or in undue strain, which would ultimately have effects the next day as well.

It is frequently asserted that because laundry workers rush out of work with much show of vigour, they are not fatigued, what is true about the statement is that they are not exhausted, but it is impossible to believe that after working for nine hours there is no fatigue present. Their general attitude might be perhaps not unfairly summed up in the expression, "I'm not tired but I'm tired of this." They are tired locally, but the chance of a change is invigorating and in the interest aroused by that change there is relief.

In some studies of other trades it has been shewn that a diminution in the number of working hours has resulted in a considerable improvement of output, particularly during the war, when very long hours were being worked. One must remember in these cases that not only were very long hours being worked, but also that the workers were working under considerable tension and emotional excitement. A feeling of disappointment is often expressed by launderers when they find that the shorter working day has not, in their case, resulted in some dramatic improvement. To those who are disappointed it is necessary to point out that the human organism has a capacity for self-protection, and that the habits of many of the older laundry workers, and also of the younger ones who copy them, are survivals from the "good old times," when very long hours were worked for very low wages. It is quite impossible to work for twelve hours at the same average speed an hour that one can work for (say) four hours, and it needs no very careful time records to reveal that in many laundries much time is wasted in the casual leisurely habits of old days. Also, it is to be noted that a decrease in the number of working hours does not take effect at once; it is some weeks before the beneficial results are shewn.*

IX—SUMMARY OF CONCLUSIONS.

(1) The present investigation deals with the effects on fitness and health of laundry work when conducted under reasonably good conditions (p. 3).

(2) Owing to the peculiar conditions of the laundry trade, continuous measurements of output could only rarely be taken, and special methods of investigation had to be devised (pp. 4, 25).

(3) Efficiency tends to fall towards the end of the day, and is often lower in the afternoon than in the morning, even during the nine-hour period of work. This effect is shewn both in the time taken to perform certain manual operations (pp. 6, 7, 14, 16), and in the results of the "dotting" tests (pp. 33, 34). Although the data available do not admit of definite conclusions to be drawn, this reduction of efficiency tends to be greater during a ten-hour period of work than during a nine-hour period (pp. 6, 7, 14, 16, 17).

(4) Large individual differences in efficiency exist, and these have a greater influence on output than any other factor studied (p. 9, 24).

(5) Slight fluctuations in health, physiological disturbances and the psychic state of the worker at the time are clearly reflected in the results of the "dotting" test (pp. 27, *et seq.*) and exert an important influence on efficiency.

(6) The arrangement of teams for work on a given task has a marked effect on the joint output (p. 22).

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* VERNON, H M (1920).—The Speed of Adaptation to Altered Hours of Work, *Industrial Fatigue Research Board, Report No 6.*

(7) Short rest pauses introduced into the middle of a four- or five-hour spell appear to have a beneficial influence upon efficiency (p. 21).

(8) The atmospheric conditions of laundries seem to compare very unfavourably with certain other industries, and much room for improvement exists (p. 43)

(9) There is no evidence that laundry work, when conducted under good conditions, is detrimental to the health of the workers (p. 47).

In conclusion, I should like to express my thanks to all the members of the trade who gave facilities for the work, and to the workers who so kindly allowed their work to be observed and timed ; in particular, I am very much indebted to Mr. R. F. Brett, of the Clissold Laundry, and Mr. Barry Neame, of the Savoy Hotel Laundry, who offered special opportunities for research in their works.

APPENDIX.

Instructions for using the Kata-Thermometer.

The cooling power of the air is estimated by means of the kata-thermometer, an instrument designed to measure its own rate of cooling at a temperature approximately that of the human body It consists of an alcohol thermometer with a large cylindrical bulb about $1\frac{1}{2}$ in. long, and $\frac{3}{4}$ in. in diameter The stem, which is graduated in tenths of a degree from 95° to 100° F., has at the top a small bulb which acts as a safety overflow when the thermometer is heated Readings with the dry kata are taken as follows :—

The bulb of the kata-thermometer is immersed in water having a temperature of about 180° F., until an unbroken column of the spirit has risen half way up the safety bulb. The alcohol rises slowly at first, but this slow movement is followed by a sudden rise, and care is necessary in order to avoid fracture of the safety bulb. The instrument is allowed to cool for a minute so as to enable the glass to get into equilibrium Then the bulb is re-heated as before, and after bulb and stem have been wiped quite dry, the kata is placed in the desired position, preferably suspended from a stand. The time in seconds which is occupied by the thermometric liquid in falling from 100° to 95° F. (*i.e.* through a range of temperature approximating to that of the human body) is noted by means of a stop watch. From three to five readings are, as a rule, sufficient for calculating an average rate of fall, from which the rate of cooling is estimated, though a larger number of observations of rates of fall is advisable when the kata-thermometer is used in positions where puffs of wind alternate with calm intervals.

The average time of fall thus obtained gives an indication of the rapidity with which heat is lost by the particular instrument used, but owing to such variables as the thickness of the glass, and slight variations in surface area, two different instruments would give different times of fall, even under identical circumstances and methods of experiment Readings are standardised, so that the rate of heat lost can be expressed in heat units per unit area per second, by using a " kata factor " ascertained for each instrument before it leaves the maker ; this factor, which is stamped on the stem near to the top bulb, is found by determining the water equivalent of the thermometer, and actually represents the amount of heat in milli-calories per square centimetre of surface required to raise the thermometer from 95° F. to 100° F. Hence by dividing the factor by the number of seconds taken by the fluid in falling through this range of temperature, the rate of heat loss in milli-calories per square centimetre per second is obtained.

> *Example.*—Suppose that the average of five readings of the time taken by the column to fall from 100° F. to 95° F. is 91 seconds, and that the kata factor marked on the stem of the instrument is 476. Then 476 is divided by 91, giving 5·2, which is taken to represent the cooling power of the air at that time and place.

It should be noted that when the temperature of the air exceeds 95°, the cooling power cannot be estimated, and is in fact zero or even a negative quantity Even at somewhat lower temperatures the estimation is difficult, owing to the long time required by the column to fall. In such instances, it is generally sufficient to note that the cooling power is less than a specified value (such as 2), and this practice has been followed in the present report.

For the calculation of " air velocity," the *temperature* as well as the cooling power of the air is required. It is, in fact, desirable whenever kata readings are made to obtain simultaneous readings of the temperature (if possible both dry and wet bulb) both inside the building in the same part where the kata is used, and outside the building in the open air.

To obtain the air velocity (in feet per minute) the cooling power of the air (determined as described above) is divided by the difference between 97·7 and the observed temperature in degrees Fahrenheit. The resulting

quotient is looked for in the table given below in one of the columns headed $\frac{H}{\theta}$, and the figure opposite in the column marked V is the value required. If the quotient is intermediate between two values of $\frac{H}{\theta}$, the value of V can be easily estimated by interpolation.

Example —Suppose that in the example already given, the observed temperature of the air was 75·5° F. The cooling power, 5·2, is divided by 97 7—75·5, *i e* 22·2, giving 0·234 This figure is intermediate between 0·23 and 0·235 in the first column of the table, and it can be easily seen that the corresponding value for the air velocity is 60 feet per minute

Air velocities for varying values of $\frac{H}{\theta}$ (British Units).

$\frac{H}{\theta}$	V.	$\frac{H}{\theta}$	V.	$\frac{H}{\theta}$	V.
·155	8	·275	106	·39	280
·16	10	·28	113	·395	289
·165	12	·285	120	·40	298
·17	14	·29	127	·405	307
·175	16	·295	134	·41	316
·18	19	·30	141	·415	325
·185	22	·305	148	·42	335
·19	25	·31	156	·425	345
·195	28	·315	164	·43	355
·20	32	·32	172	·435	365
·205	35	·325	181	·44	375
·21	39	·33	190	·445	386
·215	43	·335	198	·45	396
·22	47			·455	406
·225	52	·345	207	·46	417
·23	56	·35	214	·465	428
·235	61	·355	222	·47	439
·24	66	·36	230	·475	450
·245	71	·365	238	·48	461
·25	76	·37	246	·485	473
·255	82	·375	254	·49	484
·26	88	·38	262	·495	496
·265	94	·385	271	·50	508
·27	100				

Note —The above table is based on the following formulae, giving the relation between dry kata cooling power, temperature and air velocity :—

For air velocities greater than 8 but less than 200 ft per minute

$$\frac{H}{\theta}=(0\cdot 11+0\cdot 016\sqrt{V})$$

For air velocities greater than 200 ft. per minute.

$$\frac{H}{\theta}=(0\cdot 072+0\cdot 019\sqrt{V}).$$

where H=dry kata cooling power (found by dividing the "kata factor" by the time in seconds taken by the fluid in falling from 100° to 95° F.).

$\theta=(97\cdot 7-t)$ where t=air temperature in degrees Fahr

V=air velocity in feet per minute.

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PREFACE.

The Board in their First Annual Report gave an outline of the problems confronting them during the early stages of their work, which lay in a field at that time almost unexplored, and explained the considerations which they took into account when settling their initial procedure. The Board eventually decided that the best prospect of advancing the objects they had in view lay in devoting for a time their main resources to a series of inquiries into certain industries, chosen under the advice of the Home Office as possessing certain features which made them specially suitable for investigation. Amongst the industries so selected, a prominent place was taken by cotton, for the following reasons:—

(i) The importance of the trade as the largest textile industry.
(ii) The standard hours worked, equivalent (at the time the suggestion was made) to the maximum permissible under the Factory Act of 1901, viz., 55½ per week.*
(iii) The special conditions attaching to the industry, such as heat, noise, and humidity, which tend to make it particularly trying and have given rise to much complaint.
(iv) The variety of processes involved, affording an opportunity for studying work of different kinds
(v) The divergence of opinion existing as to the optimum spell of work.

The Board accordingly resolved early in 1919, to start an extensive investigation into the cotton industry, and to entrust its direction to Mr. S. Wyatt, M.Sc., who was stationed at Manchester for the purpose. As the first step, a preliminary survey of the whole industry was undertaken by Mr. Wyatt, in order to ascertain which of the numerous processes involved appeared most suitable for study. The results of this survey, which were published in 1920,† showed that of all the main processes weaving offered the most scope for investigation, since here production depends to an appreciable extent on the human factor, and accordingly any variations in working capacity on the part of the operatives, due to hours of labour or to the conditions of work, will be reflected in some degree in the output. Attention has, therefore, been directed since then almost exclusively to weaving, and the present report embodies the results of the main investigation, which is based chiefly on output readings, taken hourly on 261 Lancashire looms and twice daily on 344 Northrop looms, over a period of one year, certain special conditions being observed in the sheds throughout the investigation.

Owing to the magnitude of the industry and to the many

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* Before the investigation was started the hours of work in the cotton trade, in common with most other industries, were reduced to 48 per week

† Wyatt, S (1920) :—Individual Differences in Output in the Cotton Industry. *(Ind. Fat. Res. Board, Report No. 7.)*

types of manufacture comprised in it, any group of weaving sheds which might be regarded as in any sense a real sample of the whole industry, would have been far too large to admit of the detailed and laborious observations forming the basis of the present inquiry. It was, accordingly, necessary to make a selection of sheds, and under the advice of representatives of the trade, those were chosen which offered the best facilities. All of the sheds so selected—nine in number—were found to possess a high standard of efficiency. Whilst, therefore, the inferences drawn from the results are strictly speaking applicable only to the sheds under observation, and it would be unjustifiable to imply that conclusions reached through a study of only nine sheds necessarily extend to the industry as a whole, the Board think it not unreasonable to assume that some of the unfavourable tendencies which are shown to exist in these sheds will recur, and will probably be accentuated, in others in which the work is carried on under poorer conditions.

On the other hand, most of the inferences are based on very extensive data (more than 1,000,000 readings in all). As the result, sporadic and individual variations are eliminated in the final results, and only general tendencies appear; but having regard to their volume, the data involved, when treated by appropriate statistical methods, suffice to ensure that these tendencies are real, and not merely apparent or open to any reasonable doubt. The occurrence of some of the effects observed is indeed, the Board believe, already known to the industry; in such instances, the chief value of the investigation lies in raising them from a qualitative to a quantitative basis by enabling definite numerical values to be attached to them.

The Board think it desirable to invite attention to some of the more important practical points which emerge from this investigation. Probably the most notable feature is the high and uniform standard of productive efficiency reached in all the sheds under investigation (p. 7).* This naturally varies with the class of cloth woven, but even when the mechanical element, on which output depends to the extent of about 90 per cent., is eliminated by calculation (p. 34), the time spent by the weaver in doing his share in production has been shown to vary by only about half a minute in the hour—an amount which has no material effect upon total output, although it is significant from the point of view of fatigue study. In the opinion of the Board, this must be regarded as striking evidence both of the high mechanical and technical standard maintained, and of the ability and energy of the cotton operatives.

This very uniformity in efficiency (which may perhaps have been accentuated by the unusual seasonal conditions prevailing

* This statement refers to the general tendencies shown after treatment of the mass data. In the case of individual weavers considerable differences in efficiencies are apparent (p. 28), a fact which points to the desirability of some form of vocational selection.

during the year in question, as well as by the type of shed selected for investigation) has tended to increase the difficulty of tracing the influences of the different variables operating. Some of the effects disclosed in the results seem, however, to the Board to be definitely established, more especially as in some instances similar effects have been observed in other independent inquiries. It is, for example, generally accepted that production is stimulated physically by a high temperature and a high relative humidity, and in the present report (p. 17), evidence is given to show that efficiency tends to vary directly as the product of their numerical values. When, however, high temperatures are reached, the unfavourable physiological effects of the atmospheric conditions are reflected in the efficiency curves; a comparatively heavy reduction occurs towards the end of the afternoon spells, and is apparent in an increasing degree after a temperature of about 75° F. (dry-bulb) has been exceeded (p. 41). In other words, under such conditions the onset of fatigue is more pronounced. A similar effect has been observed in the case of fine linen weaving,* in which it has been shown that whereas normally the afternoon efficiency is higher than in the morning, this order is reversed whenever the wet-bulb temperature reaches about 73° F. Further, these limits of temperature correspond very closely with the temperature generally accepted by physiologists as that at which working disability begins.† It follows, therefore, that apart from other considerations, too high a temperature is uneconomic and results in diminished production, notwithstanding its favourable physical effect on the yarn

The Board suggest that much valuable information would be obtained if individual employers were to carry out their own observations on the lines described in the report, and so ascertain how far the efficiencies maintained in their sheds attain to, or fall short of, those observed in the present investigations—account, of course, being taken of the class of cloth manufactured.

Some information has also been gained as to the influence of artificial lighting on production. In previous reports of the Board,‡ the importance of lighting in weaving has been shown by the fact that in fine weaving (such as cambric or silk) output may fall as much as ten per cent. during periods of artificial light. In cotton weaving where the yarns are usually coarser, this effect is naturally not so marked, but in the present investigation a reduction of five per cent. has been observed in certain sheds (p. 22). The Board suggest that this question of illumination is well worth the attention of the industry, more especially as the fact that in one of the sheds investigated no difference was

* WESTON, H C. (1922) .—A Study of Efficiency in Fine Linen Weaving. (*Ind Fat Res Board, Report No* 20).

† Departmental Committee on Humidity in Cotton Weaving Sheds Minutes of Evidence. Cd 4485. 1909 pp 213, *et seq*

‡ ELTON, P M (1921) .—A Study of Output in Silk Weaving during the Winter Months (*Ind Fat Res. Board, Report No* 9).

noticeable, seems to imply that artificial lighting need not necessarily be inferior to natural.

Another practical question on which some information has been obtained is the comparative merits of the one- and two-break day systems of employment. The present report indicates (p. 9), that under the two-break system, the efficiency during the pre-breakfast spell is abnormally low (by approximately two per cent.) and that on this account for the given length of day the one-break system is probably better.

Finally, the Board desire to point out that the investigation described in the present report, although on an extensive scale, was conducted on a strictly observational basis; that is to say, with the object of disclosing matters of general and scientific importance, and not of studying or developing any points emerging (of the kind to which attention has already been directed), from the point of view of direct application to the cotton and other textile trades.

The Board hope that the industry may be disposed to give careful consideration to the suggestions outlined above, and whilst they feel themselves precluded from continuing unaided the study of questions ostensibly of material interest to only one group of trades, they would welcome, as they have already stated in their Second Annual Report, any scheme of co-operative action that might commend itself to the cotton industry.

In conclusion, the Board would express their deep sense of obligation, both to the managements of the sheds under observation, who have not only given facilities for the investigation but have also actively co-operated by consenting to keep certain looms confined to one class of cloth throughout a whole year, and also to the operatives concerned, who on being informed of the objects of the inquiry willingly consented to work under somewhat unusual conditions.

The Board are also much indebted to the Committee on Industrial Health Statistics for valuable criticism, and to the following Committee, formed to control and supervise the investigation since its inception :—

Mr. Kenneth Lee, LL.D.
Mr. R. R. Bannatyne, C.B.
Professor E. L. Collis, M.D.
Professor Winifred Cullis, D.Sc.
Mr. John Jackson, O.B.E.
Dr. C. S. Myers, M.D., F.R.S.
Mr. Cephas Speak, J.P.
Mr. John Taylor.

VARIATIONS IN EFFICIENCY IN COTTON WEAVING.

By S. Wyatt, M.Sc., *Investigator to the Board.*

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I. INTRODUCTION.

As the result of a preliminary survey[1] of the cotton industry, it was decided that an extensive investigation into the weaving of cotton cloth be undertaken.[2] The reasons for selecting weaving in preference to other processes were first, the relatively greater part played by the human factor, secondly, the special importance of this section of the industry, in consequence of which the results obtained will be of very wide interest and may have far-reaching effects, and thirdly, the variations in the conditions of employment and nature of the work in different branches of the trade, affording a wide choice in the selection of sheds for observation purposes. Further, the effect of the atmospheric conditions in humid[3] weaving sheds upon efficiency and fatigue has long been the subject of controversy between operatives and employers.

An attempt has been made to determine the nature and general effect of the factors which influence the efficiency and fatigability of the operatives. This will enable an enumeration and classification of such factors to be made, and later it might be possible to isolate and control each factor in order to determine its exact effect. Thus the present investigation is really concerned with existing conditions, and emphasis must necessarily be placed on this aspect rather than on the effects of modifications in methods and conditions of work. Probably, therefore, the results will merely express more definitely and accurately many facts which are already known in a general way, but reliable information must first be collected before the effects of future changes can be closely estimated.

Since the weaving section of the industry comprises such a wide and varied field, it was thought advisable to limit this inquiry as far as possible to the simplest conditions, represented by the manufacture of plain cloth. The weaving of fancy cloth is a complex process, and introduces many complications which it is desirable to avoid at this stage of the work. Even in the manufacture of plain goods, the operation is affected by many variables, and it was necessary to limit the investigation to those mills in which the least number of disturbing influences appeared to exist.

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[1] "Individual Differences in Output in the Cotton Industry" (*Industrial Fatigue Research Board, Report No 7*)

[2] The investigation occupied the latter part of 1919 and the greater part of 1920

[3] A "humid" shed is one in which the atmosphere is humidified by artificial means A "dry" shed contains only natural moisture.

II. CONDITIONS OF WORK AND METHODS EMPLOYED.

After many employers in different parts of Lancashire[1] had been consulted, ten sheds were eventually chosen. These included both humid and dry sheds containing ordinary looms and humid sheds containing automatic looms.

(*a*) **Humid Sheds containing Ordinary Looms.**

These sheds (A, B, C, D, and E) formed the main part of the investigation, and the management at the outset agreed to provide the following conditions —

(*a*) that 40 to 60 looms should be available for the purposes of this investigation for a period of twelve months.

(*b*) that during this period, the same kind of cloth should be produced on these looms.

(*c*) that, in general, the conditions under which these looms were worked should be kept as constant as possible.

The maintenance of these conditions was particularly necessary for the determination of seasonal variations in efficiency.

Before work was started in any shed the investigator explained its nature and purpose to the operatives concerned and suitable remarks were also added by the local trade union secretary in each town.[2] By these means the sympathy and co-operation of the operatives were obtained and the work proceeded smoothly and normally throughout.

Details connected with the looms under observation in the humid sheds containing ordinary looms are given in the following table :—

TABLE I.—*Particulars of humid sheds containing ordinary looms.*

Shed	No. of Looms	Looms per Weaver	Power used.	Width of Looms.	Average Speed (picks per min).	Particulars of Cloth Woven.
A	63	3	Electric	48 in	196	Plain Mull Dhooties.
B	40	4	Steam	44 ,,	189	Shirtings.
C	98	4	Steam	45 ,,	197	Bleaching Goods, 34's x 36's weft, ring spun.
D	39	3	Steam	45 ,,	194	Plain Calico 28's weft, mule spun.
E	21	3	Electric	45 ,,	199	Plain Calico, mule spun.

A few of the looms in shed A were in charge of two loom weavers, but otherwise the conditions were as given in the table.

[1] The writer here desires to acknowledge his obligation to the employers and operatives in the sheds concerned for the facilities and co-operation given throughout the investigation

[2] The writer is greatly indebted to the Secretaries of the Weavers' Associations in Bolton, Preston and Blackburn for their invaluable assistance at the beginning of this investigation.

Owing to the larger number of looms in shed C, absolute uniformity could not be maintained in the yarn used, but the amount of variation between any two looms at the same or different times was small, and the effect upon the results obtained relatively insignificant.

Since one of the aims of this investigation was to study the existence of fatigue in the operatives and to determine the nature and extent of individual variations in efficiency, a mode of procedure was adopted which would give an accurate record of the output over short periods of time. Probably the most suitable instrument for this purpose is the pick recorder, which registers the number of picks[1] woven, and thus gives an accurate record of the amount of cloth produced. One of these instruments was fixed to each of the looms selected in sheds A, B, C, D, and E.

In order to obtain a fairly representative record of the variations in output throughout the working day, readings from the pick recorders were taken at regular and frequent intervals, and an assistant was appointed for this purpose in each shed. In previous investigations, the hour has usually been taken as the most convenient unit of time, and this unit was used in the present inquiry.[2]

The hours of work were :—

Monday to Friday	7.45—12.15	1st spell.
	12.15— 1.15	dinner.
	1.15— 5.30	2nd spell.
Saturday.. ..	7.45—12.0.	

This system of the one-break day had been in operation since July, 1919, when the hours of work in the cotton industry were reduced from 55½ hours to 48 hours per week.

Whenever the hourly output of a loom was affected by a mechanical breakdown or other unusual stoppage, it was excluded from the results. For this reason, the loom efficiencies given in this report will be slightly higher than those obtained in actual practice. Any criterion adopted for the retention or rejection of results must necessarily be arbitrary, but the procedure adopted in this investigation seemed to be the most equitable.

In almost all the tables contained in this report the output is expressed as a percentage of that which is theoretically possible when the looms are running continuously. Thus in shed A it is possible for each loom to weave 196 picks per minute or 11,760 per hour (assuming that no stoppages occur). Hence if the actual output were 9,500 picks per hour the efficiency would be given as 80·8 per cent.

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[1] A " pick " is the name given to a thread which runs from side to side, or crosswise in the cloth, and a Pick Recorder is an instrument which registers the number of picks in any given length of cloth.

[2] The method of correcting the pick recorder readings is given in Appendix I.

(*b*) Humid Sheds containing Automatic Looms.

Two sheds (F and G) were included in this part of the investigation. Details of the conditions existing in each shed are given in the following table :—

TABLE II.—*Particulars of humid sheds containing automatic looms.*

Shed	No of Looms	Looms per Weaver	Power used	Width of Looms	Average Speed (picks per min.)	Particulars of Cloth Woven
F	200	20	Steam	40 and 32 in.	172	Printers and Sheetings 10's weft ; ring spun.
G	144	24	Steam	40 and 36 in	176	Printers and Twills 36's weft, ring spun.

Certain differences existed in the kind of cloth woven, but the effect of these was reduced by the comparatively large number of looms under consideration in each shed.

The hours of work were the same as in the other humid sheds. In sheds F and G readings were taken from pick recorders during the middle and at the end of each morning and afternoon spell of work, but owing to the large number of looms under observation in each of the sheds, the time required to take the readings during the middle of the working spells was so long and variable that the results obtained were not sufficiently reliable to be included in this report. The results given are accordingly limited to the average efficiency observed during each morning and afternoon spell of work, since the adoption of a smaller time interval was impracticable.

(*c*) Dry Sheds containing Ordinary Looms.

The chief results in this part of the investigation were obtained from an electrically driven shed (H) weaving fancy cloth. Readings were taken from a current meter which registered the power used in kilowatts. Since the power consumed is proportional to the time during which the looms are running, the readings from the current meters can be used to determine the efficiency of production. For the purposes of this investigation readings were taken every 15 minutes, and the results obtained represent the variations in efficiency of 240 looms having a width of 65 in. In this shed each weaver had charge of four looms and the conditions of work were exceptionally good.

The hours of work in shed H were the same as in the humid sheds. A few additional results were also obtained from a dry shed (J), in which a two-break day was worked.

In all the sheds the operatives were paid on a piece-rate basis and instances of the deliberate restriction of output by the

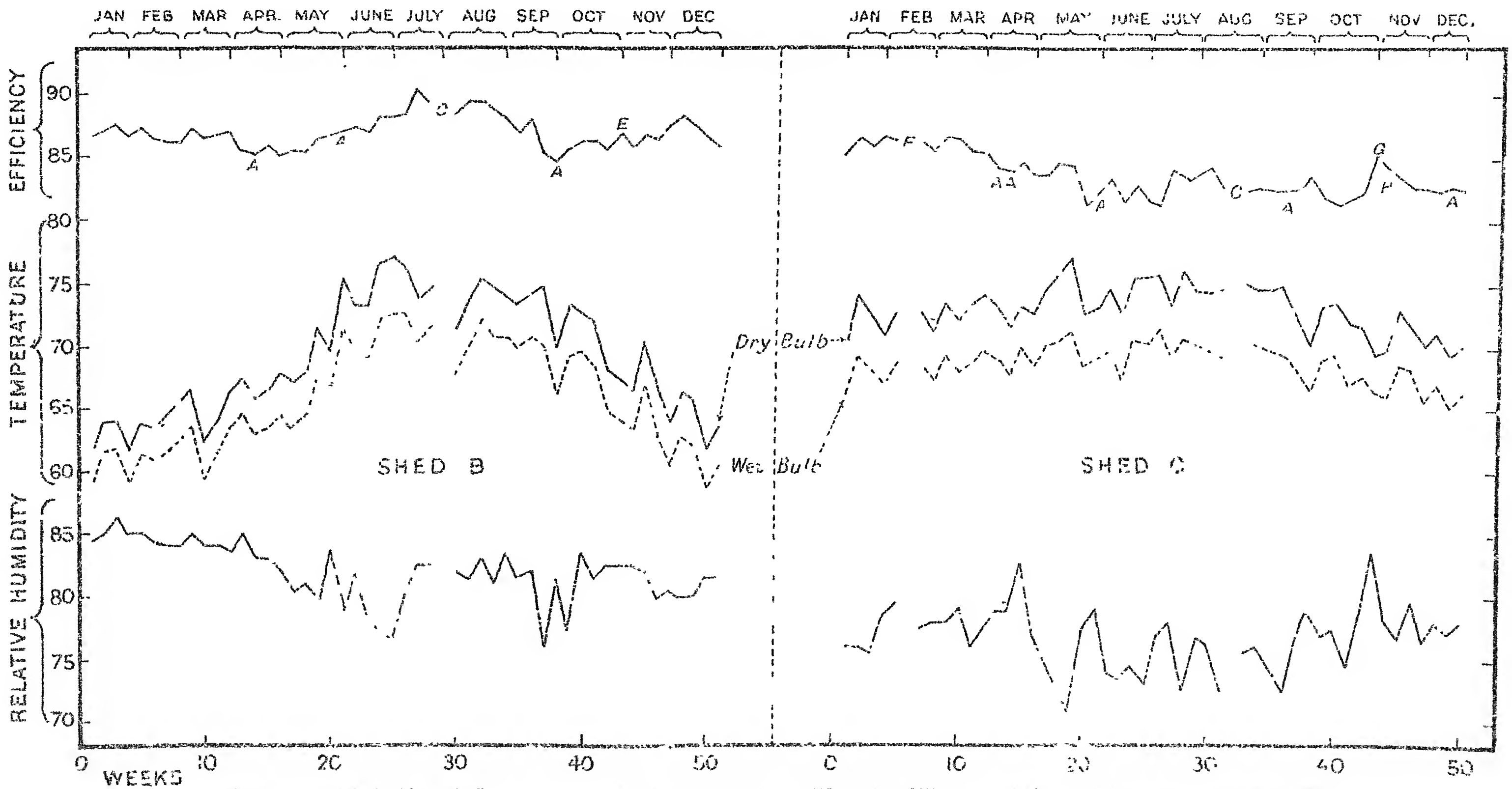

FIG. I WEEKLY VARIATIONS IN EFFICIENCY, TEMPERATURE, AND RELATIVE HUMIDITY

A = Short week (Holidays) C = Annual holidays E = Short Time (8 to 4).
F = Readings not taken G = Short Time (9 to 5) H = Short Time (7·45 to 4·30)

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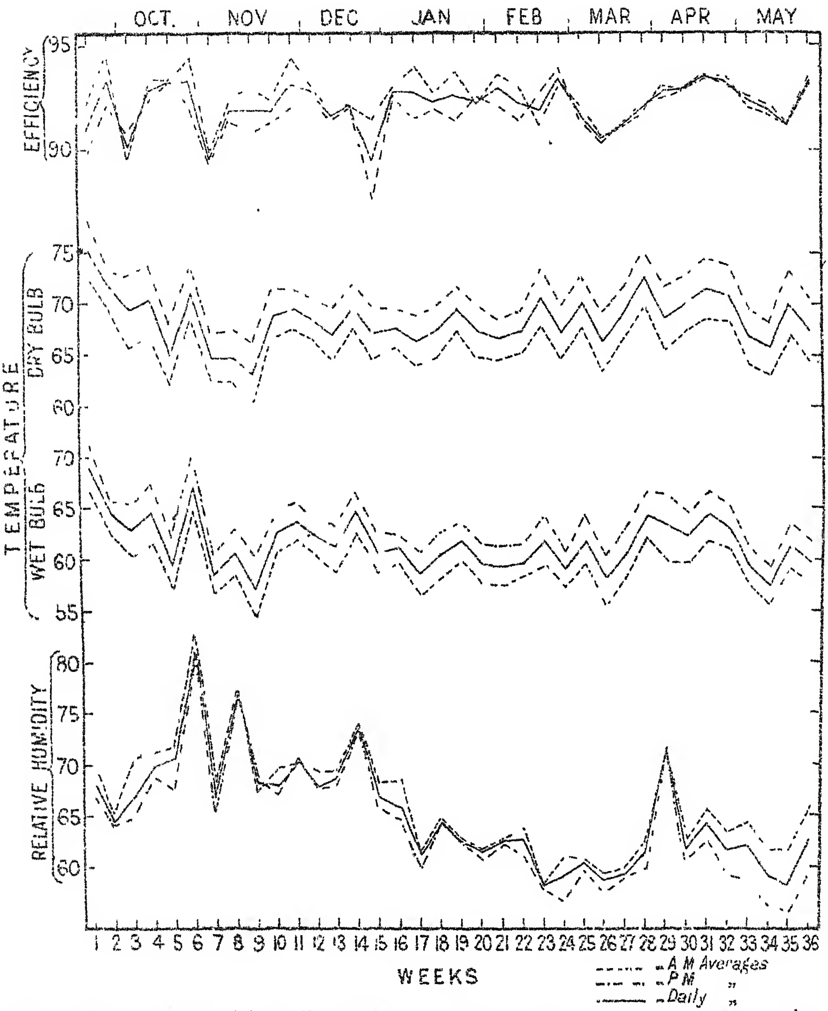

FIG. 2. WEEKLY VARIATIONS IN EFFICIENCY, TEMPERATURE & RELATIVE HUMIDITY (SHED F)

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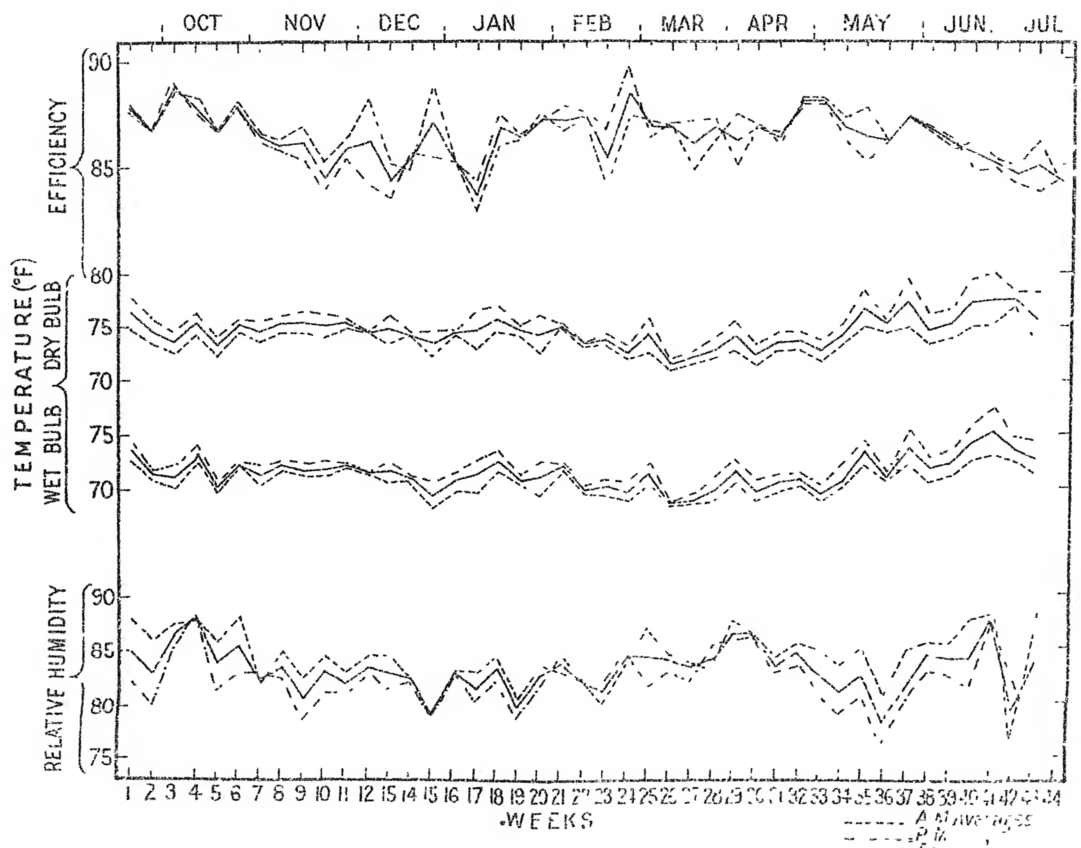

FIG 3. WEEKLY VARIATIONS IN EFFICIENCY, TEMPERATURE AND RELATIVE HUMIDITY (SHED C)

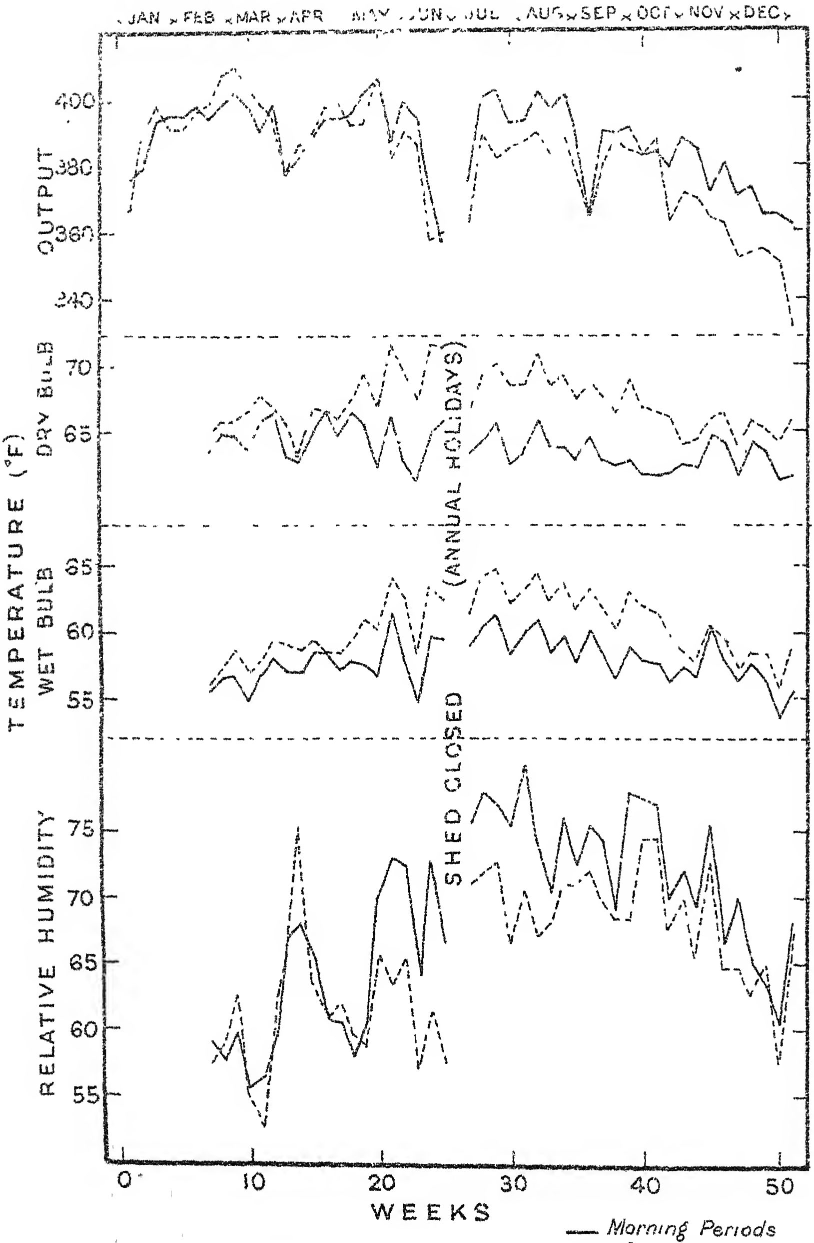

FIG. 4. WEEKLY VARIATIONS IN OUTPUT, TEMPERATURE, AND RELATIVE HUMIDITY (*SHED H*)

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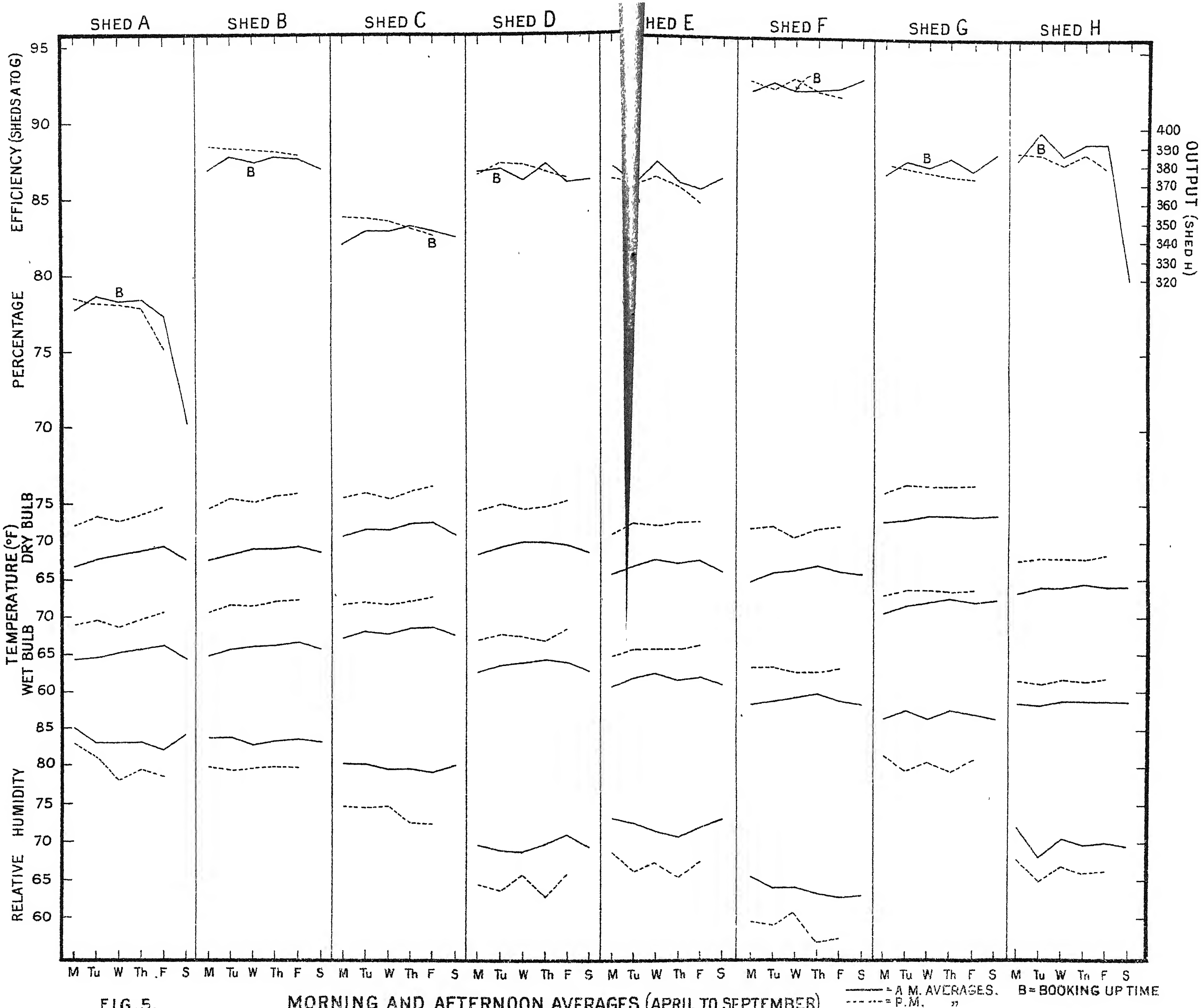

FIG. 5.

MORNING AND AFTERNOON AVERAGES (APRIL TO SEPTEMBER)

FIG. 6. HOURLY VARIATIONS DURING A COMPOSITE DAY. (APRIL–SEPTEMBER)

TEMPERATURE (°F) PERCENTAGE EFFICIENCY (SHEDS A TO G)

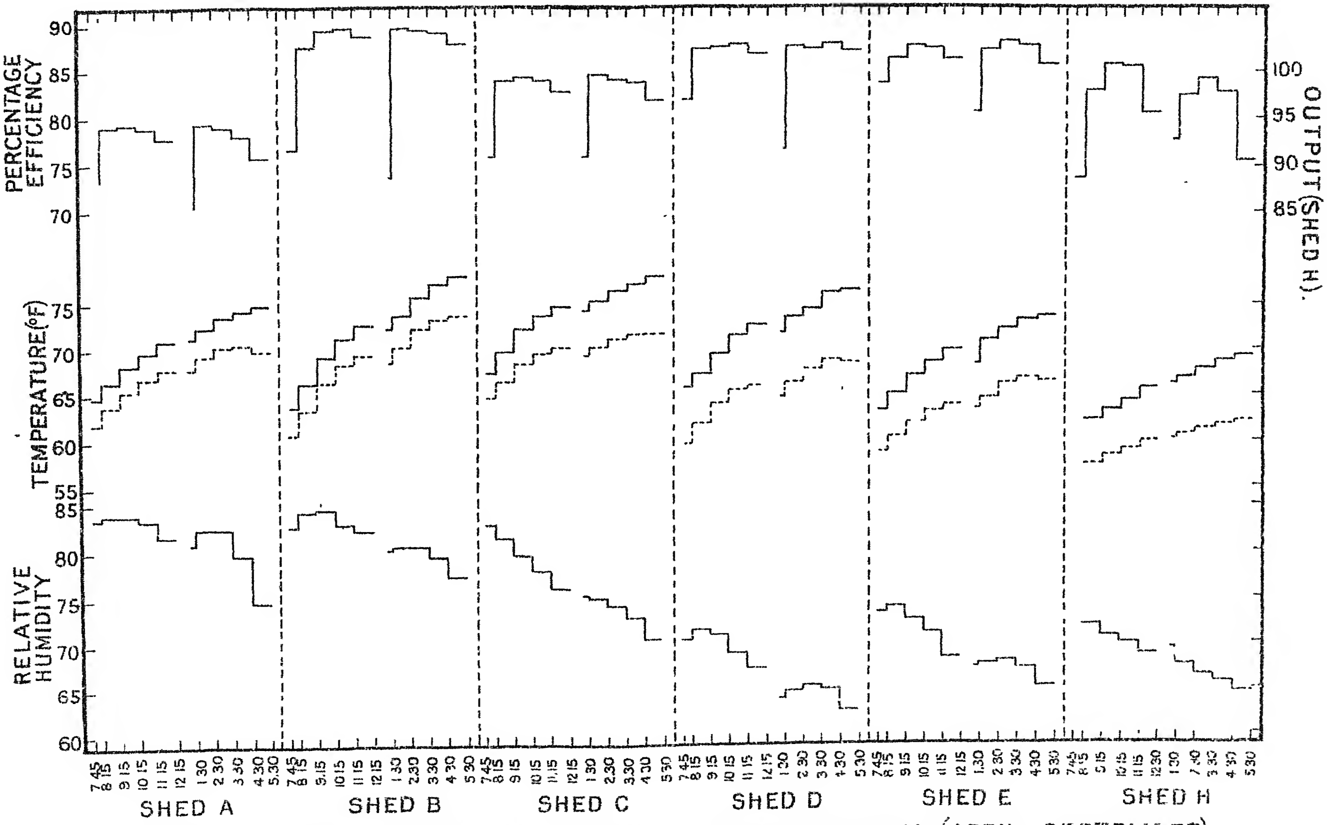

FIG. 6. HOURLY VARIATIONS DURING A COMPOSITE DAY. (APRIL-SEPTEMBER)

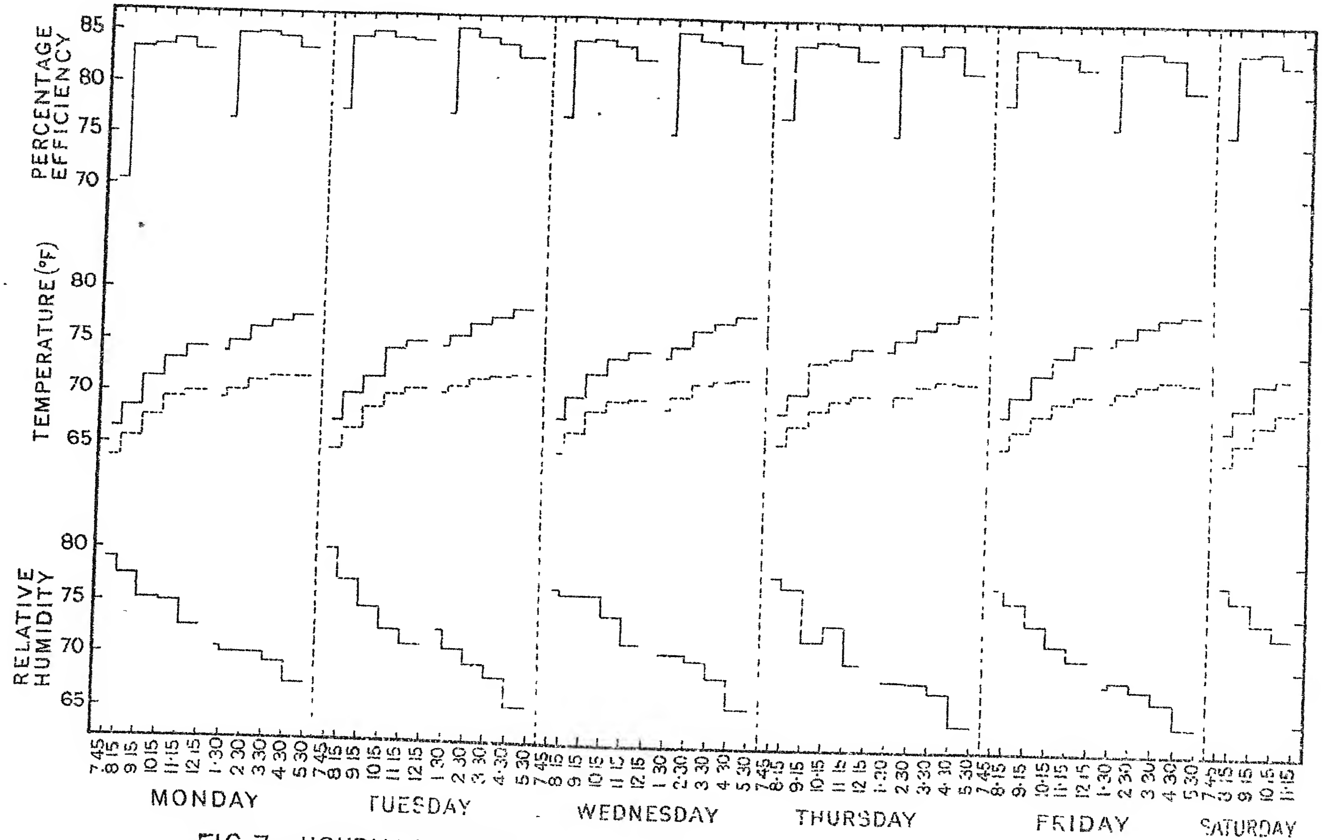

FIG. 7—HOURLY VARIATIONS DURING A TYPICAL WEEK IN SUMMER (SHED C)

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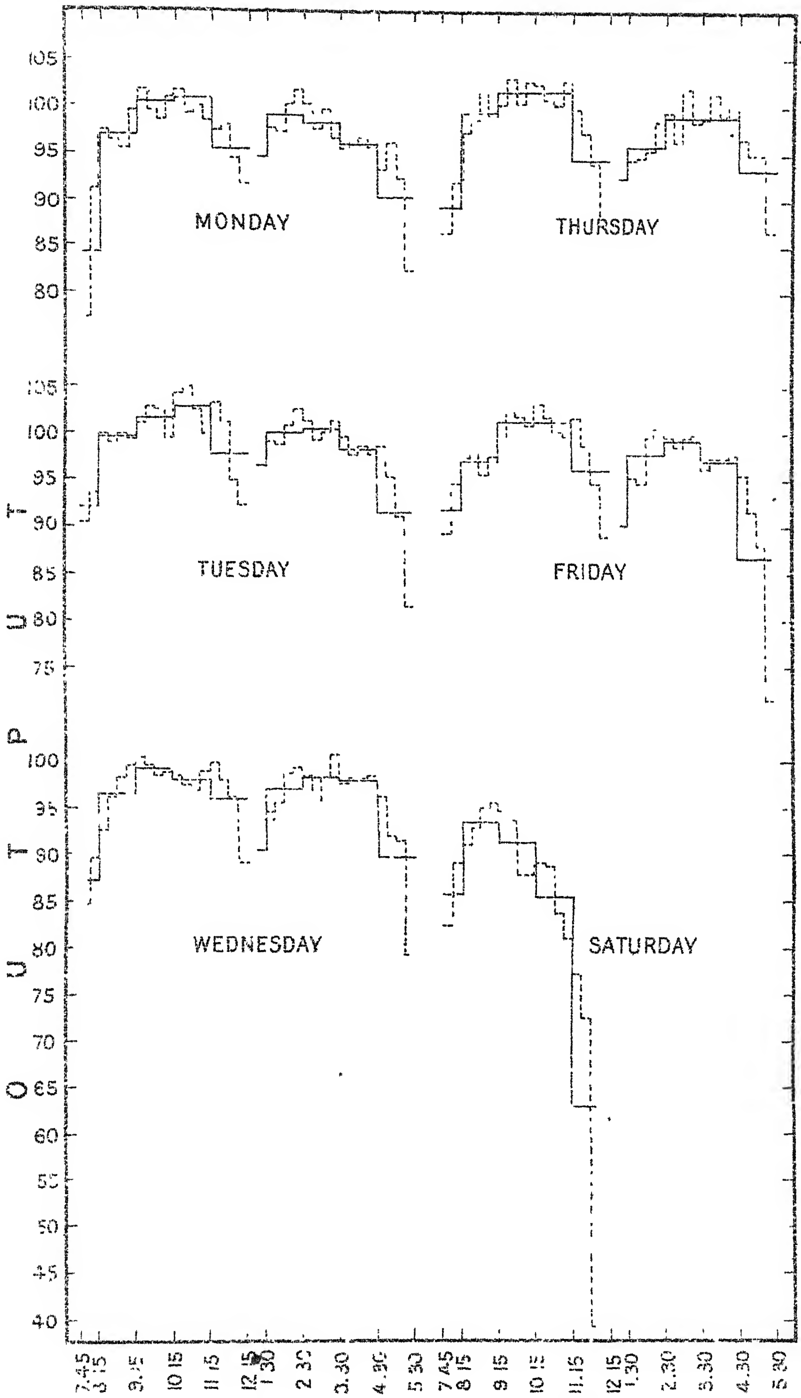

FIG.8. VARIATIONS IN OUTPUT DURING A COMPOSITE WEEK IN SUMMER (SHED H)

Broken line = $\frac{1}{4}$ hour variations.
Continuous line = hourly variations.

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workers are almost unknown in the cotton industry. Throughout the period of the investigation the operatives worked at a normal rate and the results obtained are representative of the actual conditions of work in these sheds.

III. RESULTS OBTAINED.

The results obtained have been collated in various ways, and are given in the following diagrams, which are used as the principal basis for discussion in the subsequent parts of this report.

Fig. 1.—Weekly variations (Sheds B and C).
Fig. 2.— „ „ (Shed F).
Fig. 3.— „ „ (Shed G)
Fig. 4.— „ „ (Shed H).
Fig 5.—Morning, afternoon, and daily variations (Sheds A, B, C, D, E, F, G, H)
Fig. 6.—Hourly variations during a composite day (Sheds A, B, C, D, E, H),
Fig. 7.—Hourly variations during a composite week (Shed C)
Fig 8.—Hourly variations during a composite week in summer (Shed H).

Perhaps the most obvious feature brought out is the difference in the efficiencies for the different sheds. Automatic looms, as would perhaps be expected, stand first with average efficiencies of no less than 92·2 (shed F) and 86·6 per cent. (shed G), but these are closely followed by sheds B, C, D, and E, in which plain cloth is woven and the average efficiencies vary from 83·9 to 87·0 per cent. Where fancy or coloured goods are made, the efficiency attained is much lower, as shown by the results for shed A, with an average efficiency of 77·5 per cent In shed A, for instance, dhooties are made. In this class of weaving, a coloured heading is inserted about every five yards, *i.e.*, at intervals of 50 to 55 minutes. The time so occupied amounts to about one minute and about 16 shuttle changes are involved. In addition, the fineness and character of the yarn used gives rise to a greater number of breakages. For these reasons a lower efficiency would be naturally expected, and this is recognised in the fact that the operatives receive an additional 10 per cent. to the ordinary piece-rate for plain cloth, an increase which corresponds roughly to the necessarily lower efficiency.

A second feature of the efficiency results is their uniformity in any given shed for the day, week, or year. In every case the mean variation[1] from the average is less than 1·5 per cent. This uniformity is due partly to the uniform atmospheric conditions maintained within the shed, and partly to the predominating influence of the mechanical factor.[2] Such variations as occur will be referred to later.

The efficiency curves conform as a rule to the standard type obtained for most semi-automatic processes. In the case of the hourly observations (Fig. 6), from a comparatively poor start the

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[1] The mean variation is the average of the differences between the individual values and their mean, irrespective of sign.

[2] *Cf.* "Individual Differences in Output in the Cotton Industry," by S Wyatt, M Sc (*Ind. Fat. Res. Board Report No.* 7).

efficiency increases to a maximum, and afterwards usually decreases during the working spell. Similarly, the daily curves (Fig. 5) usually show both the "Monday" effect and the low Saturday efficiency, common to most types of work. The highest efficiency tends to occur on Tuesday. The weekly curves (Figs. 1 to 4) again show certain features in common, but, with the exception of shed B (Fig. 1), not the marked seasonal variation which is apparent in certain other occupations. Uniformity was greatly assisted by the abnormally mild winter and cool summer which prevailed at the time of the investigation.

The temperature shows considerable differences between the different sheds, in regard not only to actual averages, but also to the rate of increase during the summer months (*see* Fig. 1). In all the sheds the temperature rises throughout the day (Fig. 6), rapidly at first, but more slowly afterwards, though there is a small decrease during the dinner hour. The increase is due to the following causes :—

(1) The heat produced by the machinery in motion.
(2) The artificial heating, and, in the humid sheds, the introduction of steam.
(3) The gradual rise in temperature of the outside air.
(4) The presence of the operatives.

Thus, there is an accumulation of heat in the sheds throughout the working day, and in summer the afternoon conditions at times become very trying. The decrease during the dinner hour is due to the temporary suspension of the first two and the last factors given above, and it appears probable that the subsequent afternoon temperature could be much reduced by a thorough ventilation of the sheds while the machinery is stopped and the operatives absent.[1] Any reduction in the degree of humidity in the sheds which resulted could be restored by turning on the humidifiers shortly before work is resumed in the afternoon spell.

In most of the sheds the temperature shows an inclination to rise during the week, being initially higher on each day from Monday to Friday (*see* Fig. 5). This suggests that the cooling of the shed during the night is incomplete, with the result that there is a gradual accumulation of heat which is dissipated during the week-end.

In all the humid sheds, the curves representing the dry and wet bulb temperatures are approximately parallel, because of the effort made to maintain a constant difference between these readings. In the weaving of cloth in humid sheds, it is generally believed that efficiency increases as the temperature and humidity increase, hence the desire to maintain high dry and wet bulb thermometer readings. This is usually done by forcing steam into the sheds, the amount of steam being controlled

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[1] Results bearing on this point will be found in the report on "Humidity and Ventilation in Flax Mills and Linen Factories" (Cd. 7433), 1914, p. 61.

by the thermometer readings. The Cotton Cloth Factories Act of 1911 allows a minimum difference of two degrees F. between the wet and dry bulb readings up to a temperature of 70° F., but beyond that temperature the difference between the readings gradually increases. In the humid sheds investigated the temperature readings usually approximate to the limits permitted.

The average percentage humidity for the year in sheds A and B is very high (83·4 and 82·0 per cent., respectively), but in sheds D and E it is much lower (68·9 and 68·4 per cent.). Since the amount of humidity in the two latter sheds was quite sufficient for weaving purposes, but was found to be inadequate in the former sheds, it follows that the yarn used in sheds D and E must possess characteristics which are absent in the yarn used in sheds A and B. A more detailed analysis given by the hourly variations shows, however, that there is, in fact, considerable variation in relative humidity throughout the day (*see* Figs. 6 and 7). The rise in the wet bulb temperature fails to keep pace with that of the dry bulb, especially in the later part of the afternoon spell. This is because the amount of steam admitted is restricted after the dry bulb temperature has reached 70° F. The differences between the wet and dry bulb temperatures are reflected in the humidity curves, which tend to decrease throughout the working day, especially during the summer months. In some sheds the initial high degree of humidity is maintained or even increased during the first two hours of work, but a decrease invariably follows.

In a dry shed, both the dry and wet bulb temperatures rise in the successive spells, but the former more rapidly than the latter (*see* Table IIA and Fig. 10). As a result, there is a corresponding decrease in relative humidity. Thus, a dry shed becomes hotter and drier in the course of the working day, but a humid shed still remains damp, although its temperature increases.

IV. FACTORS IN EFFICIENCY.

In common with all other industries, efficiency largely depends upon management in respect of such matters as arrangement of hours and the inter-relation of functions of operatives. The cotton trade has long been regarded as in many respects the leading industry for the more obvious requirements, and this is borne out by the high efficiency values obtained in the present investigation. The results, however, disclose certain features in which improvement may probably be possible.

In the first place, the efficiency of the early morning spell in a shed working a two-break day is low. This is shown by the data obtained from a dry shed over a period of three months in summer (Table IIA and Fig. 10).

The results (Table IIA) show that the efficiency is lowest in the pre-breakfast spell. It is 2 per cent. higher in the morning spell, and is still a little higher in the afternoon spell of work. These results refer to late summer months, and the relative efficiencies may be different in winter.

TABLE IIA.—*Average efficiency, temperature, and relative humidity for each spell during a composite day in summer (Shed J).*

Spell.	Efficiency.	Temperature (°F.)		Rel. Hum.
		Dry Bulb.	Wet Bulb.	
1	78·5	65·9	59·9	68·1
2	80·5	72·5	64·5	61·5
3	80·7	78·6	68·3	55·1

The lower efficiency in the first spell illustrates the relatively unproductive nature of work done before breakfast. The operatives begin work before having a substantial meal, and in some cases without having even a cup of tea or coffee. In addition, they are probably less punctual in starting work in the early morning, and the time lost in starting and stopping work is proportionately greater in this than in the two succeeding spells. Just as they are falling nicely into the swing of work, they have to stop for breakfast.

The results also show (Fig. 10) that the efficiency is relatively low on Monday, increases on Tuesday, and is still higher during the early part of Wednesday morning. On Thursday and Friday a decrease occurs which is most marked in the afternoon spell of Friday.

Secondly, there is a great difference in efficiencies on Saturday morning in the different sheds (*see* Fig. 5). In all the sheds the looms are supposed to run till 11.30 on this day, and the weavers are expected to sweep and clean the looms during the next half-hour. In sheds A and B the weavers begin these operations almost as soon as work begins. During the first half-hour of work the cleaning may be done for a few moments at infrequent intervals, but the intervals increase in frequency and duration as the morning progresses, and from 11 0 to 11.30 some looms may be stopped completely. In shed B some of the cleaning is done by the weavers at suitable times during the week with the result that the Saturday morning efficiency does not fall to the same extent as in shed A. In the former shed the output of a particular weaver during the hour when the operation is performed is usually reduced by about 20 per cent.

On Saturday morning in shed A the efficiency is about 7 per cent. lower than the average efficiency for the remainder of the week, while in shed H it is 13 per cent. less in winter and 18 per cent. less in summer than the average on the other mornings of the week.

In sheds C, D, and E, special people are appointed to sweep and clean the looms, with the result that the efficiency in these sheds is maintained until the end of the working week. When this system is adopted the weaver usually contributes towards the wages of the operative employed for this purpose, and the remainder is paid by the firm. This contribution by the operatives is often an obstacle to the wider adoption of the system of cleaning and sweeping, but the advantage to all concerned if the system could be more generally employed is apparent from the above results.

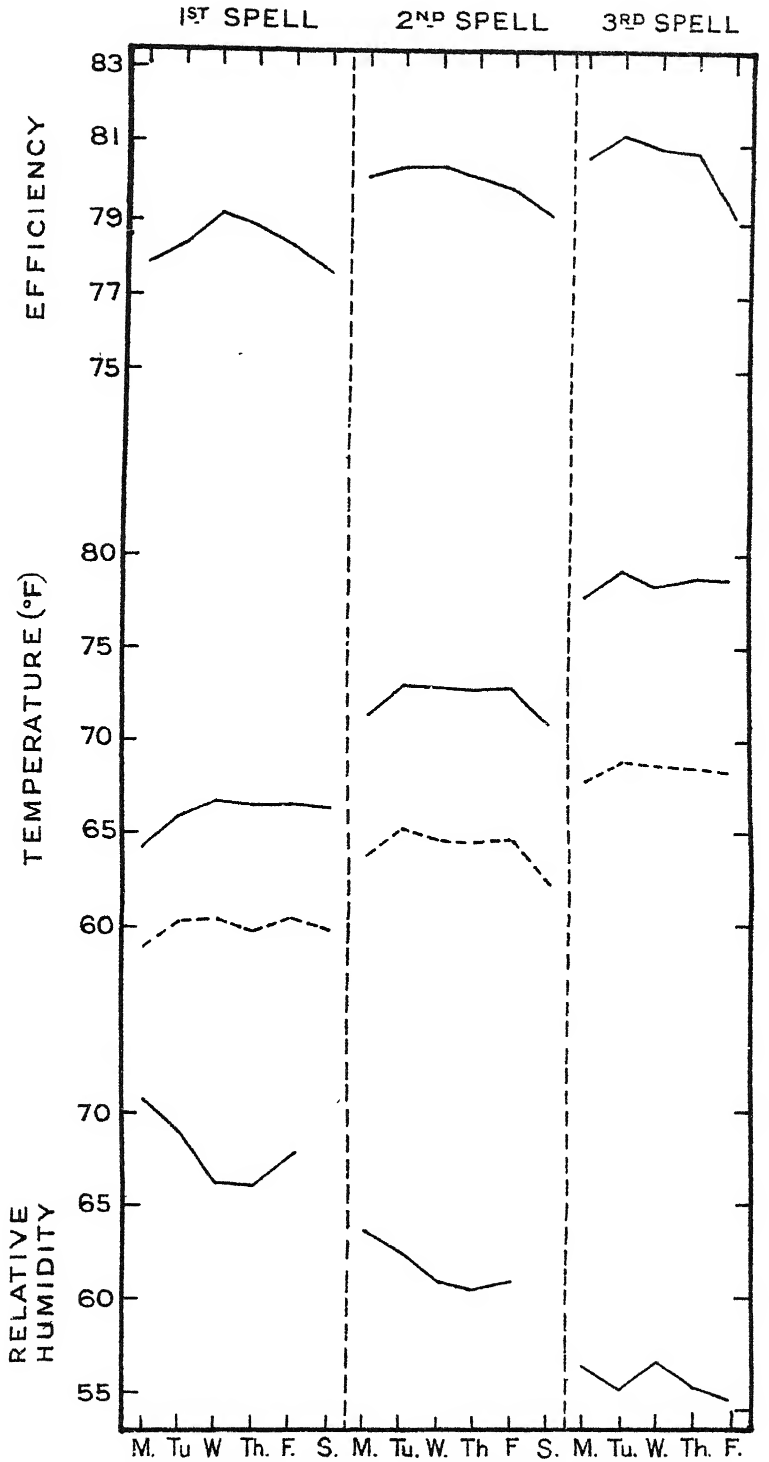

FIG. 10.—AVERAGE EFFICIENCY, TEMPERATURE, AND RELATIVE HUMIDITY FOR EACH SPELL

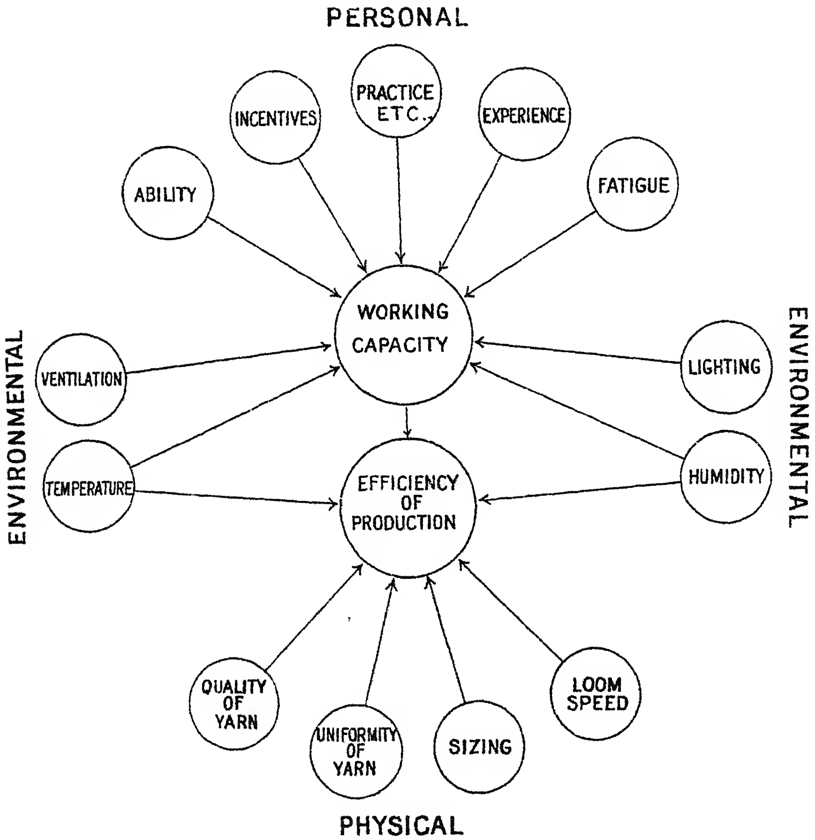

FIG. II. DIAGRAM SHOWING RELATION BETWEEN FACTORS IN WEAVING EFFICIENCY.

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In sheds F and G, the efficiency on Saturday morning is higher than usual, but this is largely due to the fact that efficiency is adversely affected at various times during the week by the cleaning and sweeping of looms while on Saturday morning these operations are not carried out.

Thirdly, the low efficiency on Monday morning is seen to be largely due to the results obtained at the beginning of the spell (*see* Figs. 7 and 8). A much better start is made on the other mornings of the week. In general, the low efficiency during the quarter or half-hour at the beginning of any working spell is due to:—

(*a*) lateness in starting work in the case of some operatives.
(*b*) loss of swing caused by the preceding break.
(*c*) comparatively unfavourable atmospheric conditions in the sheds, especially during the morning spell.
(*d*) the effect of "rest" upon the looms and warps, especially during the week-ends and nights.
(*e*) (in some cases) the cumulative effects of fatigue as the week advances.

In the cotton industry, the operatives as a whole are usually good time-keepers, and lateness in starting work is the exception. As records of the time of arrival and departure of the operatives are not kept, the actual time lost through lateness in arriving at the mill cannot be given, but the general uniformity of the individual results obtained at the beginning of each morning spell in different weeks show that the amount is insignificant.

Loss of swing or practice due to the preceding break varies in amount at different times of the week. It is greatest on Monday morning and is greater at the beginning of the morning than at the beginning of the afternoon spell. Here again, the actual effect is difficult to measure because of the simultaneous existence of other variable factors such as temperature, humidity, and the time of starting work.

The comparatively unfavourable atmospheric conditions which prevail in the sheds at the beginning of the morning spell, particularly on Mondays, are undoubtedly responsible for part of the lower efficiency observed at that stage of the working day. In most cases their influence, although progressively decreasing as the morning advances, is exerted for a greater length of time than the effects of loss of practice. During the winter months suitable temperature conditions are frequently not reached until after two or three hours of work. A higher initial temperature would undoubtedly give more satisfactory results since a low temperature means an increase in the number of yarn breakages and consequently more work for the operatives.

Apart from these general considerations, efficiency in the weaving section of the cotton industry is the resultant of many factors, some of which act directly upon the materials used in the manufacturing process, while others affect production indirectly through the working capacity of the operatives. The situation is further complicated by the existence of factors such as temperature

and humidity which have a direct effect upon the yarn used in weaving and an indirect effect upon production through their effect upon the operatives.

Efficiency in weaving depends upon the number of loom stoppages and the ability of the operative to attend to these stoppages. If the number of yarn breakages is increased by the action of the physical factors or by changes in the shed temperature or humidity, efficiency of production will be decreased accordingly. A similar result will follow from a reduction in the working capacity of the operative. The particular difficulty to be met in weaving is that factors such as temperature and humidity often tend to *increase* production by causing a decrease in the number of yarn breakages, but at the same time tend to *decrease* production by acting unfavourably upon the working capacity of the operatives.

The more important factors noted in this investigation may be classified as follows :—

A. *Environmental.*	B. *Personal.*	C. *Physical.*
1. Temperature.	1. Ability.	1. Strength of yarn.
2. Humidity.	2. Incitement and Practice.	2. Uniformity of yarn.
3. Ventilation.		3. Sizing.
4. Lighting.	3. Experience.	4. Speed of loom.
	4. Incentives.	
	5. Fatigue.	

The relation between these factors and efficiency of production may be illustrated diagrammatically, as in Fig. 11.

A. Environmental Factors.

As has been pointed out in another report,[1] the weaving of certain textiles has the special characteristic that the environment to which the operative is exposed is of great importance to the process of actual manufacture. For the successful weaving of some kinds of cotton cloth the temperature and humidity of the air must not fall below a certain point, otherwise the yarn becomes brittle and loses its elasticity, the size with which the warp is impregnated tends to dry, and the result is a large increase in the number of breakages and the production of an inferior cloth.

(*a*) Temperature.

Throughout the cotton industry it is generally believed that a fairly high temperature is necessary for the manufacture of cloth. The sheds are consequently kept at a temperature well over 60° and in some cases the average temperature for the year is from 70 to 75°. During the hot summer months the shed temperature frequently reaches 85 to 90°. In this investigation the effect of temperature on output was obscured by the small variations in temperature observed, due to the unusually mild winter and cool summer which prevailed when the readings were taken. Differences in the quality and strength of yarn also introduce irregularities,

[1] "Atmospheric Conditions in Cotton Weaving," by S. Wyatt (*Ind. Fat. Res. Board Report, No.* 21).

which become increasingly significant as the number of readings available for comparative purposes decreases. These facts have introduced difficulties into the statistical treatment of the results, which involved the evaluation of correlation coefficients. The greatest variations in temperature were recorded in shed B, and as this shed provided the least irregular series of results for statistical purposes, it is the most suitable of the humid sheds for determining the effect of temperature on output. The correlation coefficients[1] obtained show that a fairly close relation exists between temperature and efficiency of production. (Mean = 0·557). In other words a rise or fall in temperature is usually followed by a rise or fall in output, due to a reduction or increase in the number of yarn breakages. Although this statement refers specifically to the results obtained from shed B, it is possible that all humid sheds might yield similar results if the variations in temperature were sufficiently great.

In the dry shed H, the effect of temperature upon output is different from that observed in the humid sheds. The partial correlation coefficients between output and temperature are almost all negative and very small (Mean = − ·134), which means that there is a slight tendency for the output to decrease as the temperature rises. This is because there are considerable differences in the yarn used in dry and humid sheds, either in the original nature and quality or the method of treatment in the preparatory processes.

In order to compare the hourly variations in temperature in different sheds with the temperature of the outside air the records obtained at the same hour on each day during the month of August have been averaged and tabulated in Table III.

TABLE III.—*Hourly variations in temperature in dry and humid sheds and the outside air.*

Shed.	Type	8 15	9 15	10.15	11 15	12.15	1.15	2 15	3 15	4.15	5 15
A ..	Humid	66 8	68·6	70·8	72·6	74·2	74 4	75 4	76 5	77·2	77·5
B ..	,,	66 5	68 8	71·4	73 5	74·8	74 2	75 6	77 4	78·6	79 5
C ..	,,	68 4	71·1	73·6	74·8	75·7	75 1	75 9	76 8	77·4	78·0
D ..	,,	66 5	68·2	70·5	72·4	73·5	73·3	74 6	76 1	77·1	77·5
E ..	,,	64·6	66·1	67·9	69·5	70 5	70 8	71·7	73·1	73·9	74·0
H ..	Dry	62·2	64·0	65·0	65 9	66·6	67 3	68·3	69·4	70·6	71 5
J ..	,,	67·9	71·1	74·2	76 6	77·3	77 5	79·2	80·4	81·0	81·4
Outside air.		55·1	55·7	56·3	57·3	58 0	58·4	58 7	59·1	59·3	59·2

The above results are also represented in Fig. 12.

The results show that the average daily temperature in the different sheds during the month in question is from 10 to 17 degrees higher than that of the outside air. This difference

[1] *See* Appendix II.

represents the extent to which the sheds are heated while work is in progress. Even shortly after work has begun, the sheds are from 7 to 14 degrees hotter than the outside air, and as the day proceeds the temperature inside the sheds increases more rapidly than that outside. The initial high shed temperature is due to artificial heating and humidification, necessary for the manufacture of the yarn. The subsequent rise is partly due to this cause, but, in addition, is connected with the increase in temperature of the outside air, and is also influenced by the heat generated by the machinery and by the presence of the operatives.

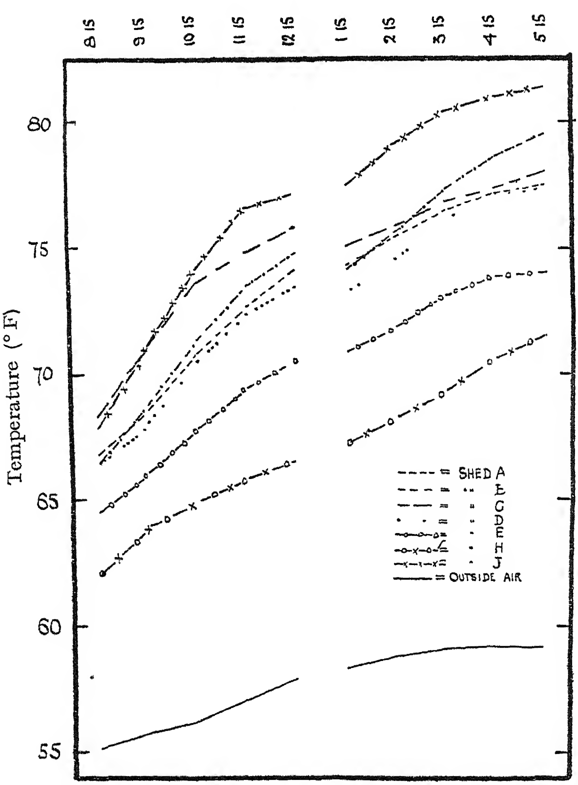

Fig. 12.—Hourly variations in temperature in dry and humid sheds and the outside air.

In all cases, the curves representing the different sheds are approximately parallel, but the temperature of the hottest shed is 9·5 degrees higher than that of the coolest. It is interesting to note that the hottest and coolest sheds (J and H) are both " dry," and since the lower temperature in shed H is found to be quite sufficient for weaving purposes, it follows that either the high temperature in shed J is unnecessary or the yarn used in this shed requires a higher temperature for efficient weaving. In any

case, the differences between the various temperature curves show that the temperature of the shed is under the control of the management to a greater extent than is generally supposed, and point to the importance of determining and maintaining the optimum temperature in each type of shed.

There is an interesting difference between the curves of sheds B and C. In shed B, the initial temperature is 2 degrees less than that of shed C, but the final temperature is 1·5 degrees higher. In the former shed steam continues to be admitted at approximately the same rate throughout the day, apart from its effect upon temperature, but in shed C it is partially controlled by the thermometer readings.

(b) HUMIDITY.

As in the case of temperature, it is generally accepted that the output in humid sheds increases as the relative humidity increases, and consequently the humidity in these sheds is usually maintained at a high level. In the present investigation it varied from 60 to 90 per cent. in the different sheds.

The effect of humidity on output was also tested by means of the correlation method, but as the variations in humidity were even less than those of temperature, the results are more inconclusive. In the case of the humid shed B, there is a small positive partial correlation (Mean = ·222), not necessarily significant, but probably so in view of the consistence of the samples. This indicates that output in this shed tends to increase as the relative humidity increases. Further indications of the dependence of output in humid sheds on relative humidity are given by the following results :—

(i) In shed A, with a temperature of 77·0°, and a relative humidity of 85 per cent., the breakages were few. With the same temperature, but a relative humidity of 63·4 per cent., the weavers complained of the cloth weaving badly. "Ends" were continually breaking out, and the operatives said this was due to the steam being turned off earlier in the day. In the former case the efficiency was 76·5 per cent., but in the latter it was only 68·9 per cent.

(ii) In another inquiry[1] a series of experiments was carried out by certain manufacturers with the object of determing the effects on weaving of different degrees of relative humidity; the results of these are summarised in Table IV, and show that the number of breakages increased as the relative humidity decreased, and that in the sheds in question a high temperature, if unaccompanied by a high relative humidity, did not suffice to maintain weaving efficiency.

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[1] Second Report of the Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds [Cd 5566], 1911, pp. 1–11.

TABLE IV.—*Showing relation between humidity and yarn breakages.*

Shed	Temperature. Dry Bulb.	Temperature. Wet Bulb	Relative Humidity.	Remarks
X ..	80–92	75	75–41	Repeated complaints from weavers. Feel of cloth absolutely spoilt. Breakages very heavy, an increase of 62 per cent. on the average
Y ..	(*a*) 78·4	74·2	78·4	Average number of warp breakages = 6 2
	(*b*) 79·3	72·8	69·0	Average number of warp breakages = 12·8
Z ..	(*a*) 77·5	73·5	79·0	Weaving "all right"
	(*b*) 79·0	72·0	67 0	Weaving gradually growing worse.
	(*c*) 81·0	73·5	66 0	Weaving at a standstill. Twist breaking out in bunches.

(iii) During the course of this investigation, the humidifying apparatus in one of the sheds broke down, and the results obtained on Thursday, when the humidifier was not in use, are compared with those recorded on the previous day (Wednesday), when the apparatus was working. The results are given in Table V, and are represented graphically in Fig. 13.

TABLE V.—*Showing relation between weaving efficiency and relative humidity.*

		7.45 – 8.15	8·15 – 9·15	9.15 – 10.15	10.15 – 11.15	11.15 – 12.15	1.15 – 1.30	1.30 – 2.30	2 30 – 3 30	3.30 – 4.30	4.30 – 5.30
Wed.	Efficiency	72·5	84·3	84·2	83·7	82·8	70·6	85·5	83 3	82·9	80·9
	Dry Bulb	64·6	67 9	71·8	73·9	74·7	74 9	75 8	77·4	78 9	79·4
	Wet Bulb	61·5	65·5	68·4	70·1	70·7	70 3	71·3	72·2	73·5	73·1
	Rel Hum	82·3	86·1	81·0	80·0	79·0	76 0	76·5	74·2	73 4	69·8
Thu.	Efficiency	72 1	84·2	83·0	82·8	81·8	67·4	81·1	81·0	79 5	71·5
	Dry Bulb	66 0	67·5	69 7	71 7	72·6	72·2	72·9	73·7	74·5	75·4
	Wet Bulb	62·5	64·0	65·0	65·1	65·4	64 9	65 3	65·8	66 0	66·0
	Rel Hum	80 5	80·5	74·5	66·6	64·2	63·8	62 6	62·4	60·0	56·4

The results obtained when the humidifier was working were similar to those of a typical day. The maximum output occurred early in the spell, but was maintained for a longer time in the morning than in the afternoon spell. The temperature rose throughout the working day, rapidly at first, but more slowly afterwards, but the difference between the wet and dry bulb readings gradually increased, *i.e.*, the relative humidity decreased as the day proceeded.

On the following day when steam was not passed into the shed, the temperature and output for the first hour were similar

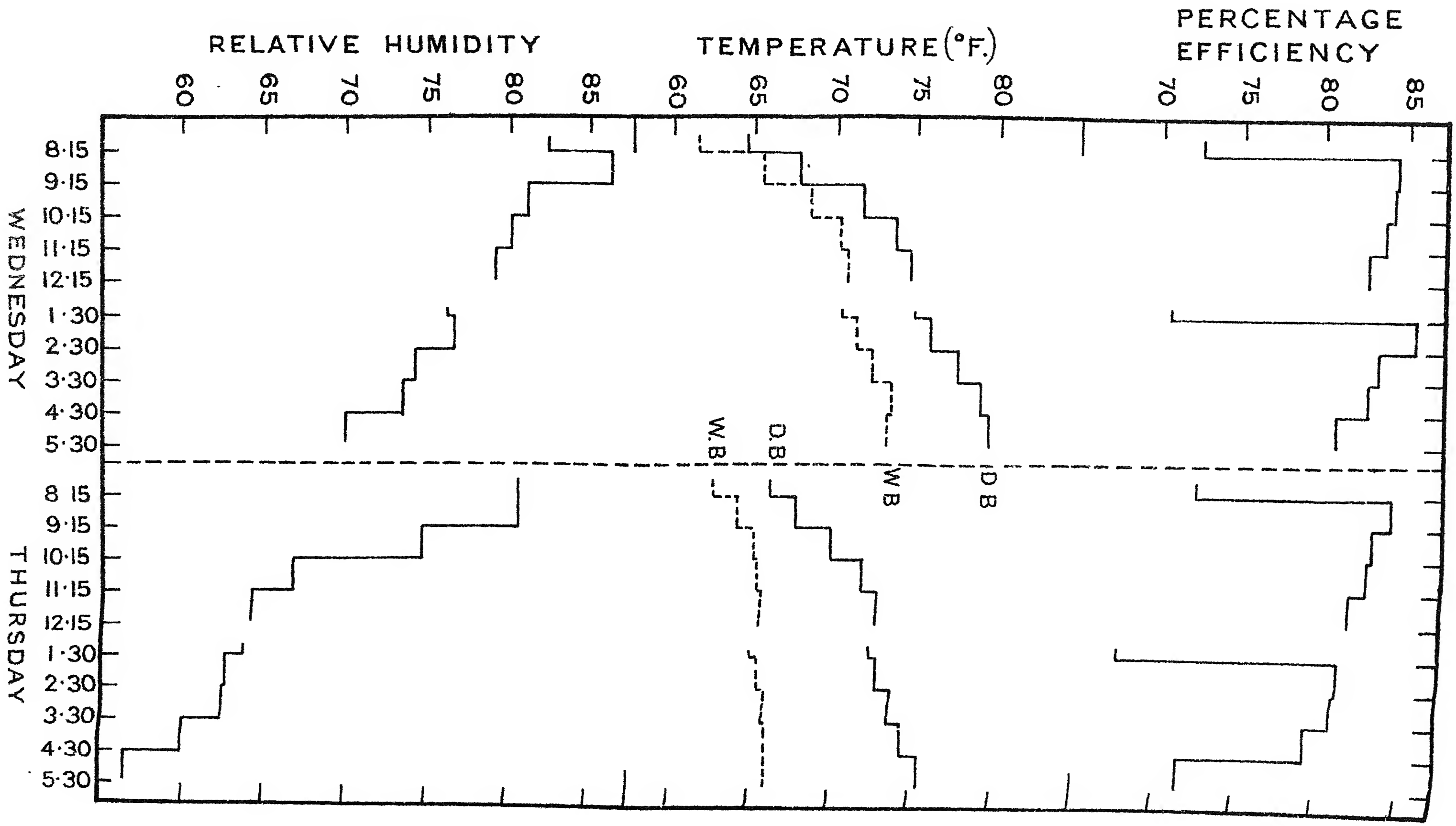

FIG. 13.—RELATION BETWEEN RELATIVE HUMIDITY AND EFFICIENCY.

to the corresponding results of the previous day, but afterwards the efficiency decreased throughout the day. This decrease was due entirely to the fall in relative humidity caused by the rising dry bulb temperature, with no corresponding rise in wet bulb temperature. In the last hour of work the output was 12·7 per cent. less than that of the best hour of the day, and the average output was approximately 3 per cent. less than that of the previous day. On the day of lower output the ends were "flying out in all directions," and although the weavers tried to cope with the unusual conditions, some of them ultimately gave up the attempt.

A comparison of the rate of increase in temperature on the two days is interesting, since it shows the effect of the admission of steam upon the temperature of the shed. On both days the outside temperature was approximately the same, but the inside temperatures at the end of each day showed a difference of four degrees Fahr.

(iv) Since output appears to vary with the temperature when the relative humidity is constant, and with the relative humidity when the temperature is constant, it seemed worth while to test how far it varies with the product of the temperature and humidity when both are variable. Shed B was selected for this purpose, and the results are given in Table VI.

TABLE VI.—*Showing relation between efficiency, temperature, and relative humidity.* (*Shed B.*)

Week No (1)	Dry Bulb Temp. (T) (2)	Rel Hum. (R.H.) (3)	T × R.H. (4)	Efficiency Calculated.[1] (5)	Efficiency Observed. (6)
15	66·6	83·0	5527	85·5	85·8
16	68·0	82·0	5576	85·8	85·2
17	67·2	80·5	5409	84·9	85·5
18	68·0	81·0	5508	85·4	85·3
19	71·5	80 0	5720	86·5	86·4
20	69·8	84 0	5863	87·3	86·8
21	75·6	79·0	5972	87·8	86·9
22	73·6	82·0	6035	88·2	87·2
23	73·3	78·5	5754	86·7	86·9
24	76·9	77·0	5921	87·6	88·1
25	77·3	76·6	5921	87·6	88·1
26	76·4	80·5	6150	88·8	88·3
27	73·9	82·5	6096	88·5	90·4
28	74·8	82·5	6171	88·9	89·3
29		Annual Holiday			
30	71·1	82·0	5830	87·1	88·6
31	73·8	81·5	6014	88·0	89·3
32	75·6	83·0	6274	89·4	89·3
33	74·8	83·0	6208	89·1	88·7
34	74·0	83·5	6179	88·9	88·1
35	73·6	81·5	5998	88·0	86·8
36	74·3	82·0	6092	88 5	88·1
37	74 9	76·0	5692	86·4	85·4

[1] This column is calculated from the equation obtained by assuming that efficiency bears a linear relation to the product of temperature and relative humidity

The results in columns (4) and (6) are further represented in Fig. 14.

The similarity between the two curves indicates the relation between output, on the one hand, and temperature and relative humidity, on the other. The unusually high output in week 27 was due to the incentive produced by the approaching annual holiday.

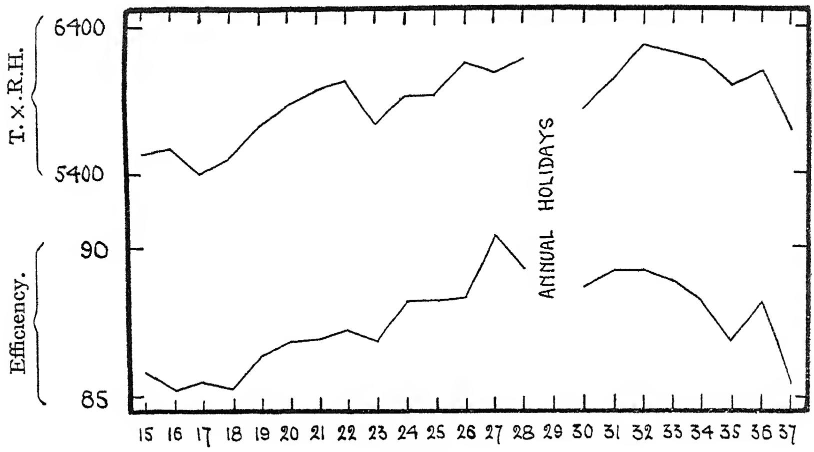

Fig. 14. Relation between efficiency and product of temperature and humidity.

In the "dry" shed H the effect of humidity on output, like that of temperature, is different from that observed in the humid sheds. Here small negative partial correlations between output and relative humidity (mean = − ·089) are shown (again not necessarily significant, but almost consistently negative), indicating that there is a slight tendency for the output to *decrease* as the relative humidity increases. In this shed the results for weeks 14 to 41 fall into two groups having approximately the same temperature, but different relative humidities. An arrangement of the results on this basis is given in Table VII.

TABLE VII.—*Showing relation between output and relative humidity. (Dry shed H.)*

Group.	No. of weeks	Average Output.	Average Temperature (°F).	Average Relative Humidity.
1	7	393	66·0	61·9
2	13	389	65·8	73·1

Thus, although the relative humidity in Group 2 is 11·2 per cent higher than in Group 1, the output is slightly less. In this shed, then, the effect of humidity on output seems to be very

different from that observed in humid sheds. The cause of the difference must again be associated with differences in the quality and method of treatment of the yarn used in dry and humid sheds.

(*c*) VENTILATION.

Special attention has been given, to this subject and the results have been published in a separate report,[1] in which it is shown that the undesirable physiological effects of high temperatures and humidities can be reduced by increasing the rate of air movement in weaving sheds.

(*d*) LIGHTING.

(i) *Proportion of Daylight and Artificial Illumination.*

During the course of this investigation questions connected with the illumination of weaving sheds have frequently arisen. These have led to the collection of a certain amount of data relating to the nature of the existing systems of illumination, and their economic and hygienic effects.

In all weaving sheds strong and uniform lighting is essential, and this is secured by means of roof lights, which usually face north. In some sheds this light is supplemented by lateral windows, but these are seldom found in the more modern sheds. Although all weaving sheds have roof lights, the natural illumination within the shed varies considerably in different sheds, and in a previous investigation[2] the daylight factor[3] at the loom was found to vary from 0·2 per cent. in one shed to 5·0 per cent. in another. That is, only 0·2 to 5·0 per cent. of the external daylight is actually found there. These figures are significant, and suggest that when daylight illumination begins to fail during the winter months, artificial light must be used for a greater length of time in some sheds than in others. Some of the causes of the differences in the natural illumination of sheds will appear in subsequent parts of this report.

In the present investigation the times when artificial light was used have been noted in the different sheds, and the results obtained make possible a rough comparison of the amount of natural illumination in the respective sheds. These are given in Table VIII, and refer to the ten weeks following the Christmas holidays.

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[1] Atmospheric Conditions in Humid Weaving Sheds, by S. Wyatt (*Ind. Fat. Res Board, Report No* 21)

[2] Report of the Departmental Committee on Lighting in Factories and Workshops, 1915, Vol. I, p 43

[3] The daylight factor is the ratio expressed as a percentage between the amount of light actually reaching a given point in the shed and the amount of light which would reach that point from an unobstructed sky if the walls and roof of the building were removed

TABLE VIII.—*Showing average duration in minutes per day of artificial illumination in different sheds.*

Weeks	Shed A a.m.	Shed A p.m.	B a.m.	B p.m.	C a.m.	C p.m.	D a.m.	D p.m.	F a.m.	F p.m.
1	51	77	60	84	96	111	63	92	53	58
2	44	65	56	66	79	89	65	89	44	64
3	37	50	39	54	71	82	65	77	39	72
4	32	45	23	48	57	78	40	67	35	54
5	5	32	6	29	74	48	39	34	22	38
6	8	28	9	16	—	—	25	33	—	35
7	—	12	3	12	30	39	14	24	—	12
8	—	9	—	10	19	28	6	16	—	—
9	—	3	—	5	6	15	—	9	—	—
10	—	—	—	—	—	7	—	—	—	—
Avg.	17·7	32·1	19·6	32·4	48·0	55·2	31·7	44·1	19·3	33·3

It will be seen that there were wide variations in the duration of artificial illumination in the different sheds. This is shown not only by a comparison of the sheds in similar weeks, but also by the number of weeks during which artificial light was used. These differences may be partly due to different managerial ideas regarding the conditions when artificial light is necessary, but they are chiefly due to differences in the natural illumination of the sheds.

In this connection the construction of the shed and the proximity of high buildings are the most important factors. The ratio for each shed of floor area to roof-window area is given in Table IX.

TABLE IX.—*Showing relation between area of roof lights and floor space.*

Shed.	Floor area Roof lights
A	1 · 0·45
B	1 : 0 41
C	1 0·32
D	1 0·35
F	1 0·40

Tables VIII and IX show that there is a relation between the duration of artificial light and the ratio of roof lights to floor space in the respective sheds. In this respect shed C is the most unsatisfactory. This is a comparatively old shed, and its natural illumination is further impaired by the proximity of a spinning mill In addition the reflective power of the walls and roof of the shed is decreased because of the darkened condition of their white surfaces. Shed A is the lightest, and the beneficial effect

of the large area of the roof lights in this shed is increased by the absence of belting, since the looms have the individual form of electric drive. Thus although the natural illumination in weaving sheds may be adequate during the summer months, differences in shed construction, especially in connection with the roof lights, may have an important influence upon the duration of natural and artificial illumination during the darker months of the year.

(ii) *Artificial Illumination and Output.*

One-break day.—In order to determine the effect of artificial illumination upon output, the efficiency records obtained in shed D during the weeks under consideration have been analysed and the results obtained are given in Table X. This shed has been chosen because it provided a continuous period of work under uniform conditions, and was one of the darker sheds included in this investigation.

An investigation in the silk industry[1] has shown that the weekly output increases during the first three months of the year, and the increase has been attributed to the decrease in the duration of artificial illumination in successive weeks. In cotton weaving the weekly output may remain the same or even decrease during this period because of the variations in the shed temperature and relative humidity. The efficiency results have accordingly been arranged to show the average hourly variations in output during the day in successive weeks. Thus although the average temperature and humidity may be different in different weeks, the extent of the hourly variations in temperature and humidity is approximately the same in consecutive weeks. If, therefore, temperature and humidity were the only factors affecting output, curves representing the average hourly output at corresponding times in successive weeks should be approximately parallel. Deviations from this condition will be due to the influence of some other factor or factors, and the most important additional factor operative during the period under consideration appears to be lighting.

During the first three months of the year the duration of artificial light progressively decreases. Throughout the period it was never used between the hours 9.15 a.m. and 3 30 p.m., hence the results in Table X and Fig. 15 give hours free from artificial light and others in which the duration decreases in successive weeks. The hours most affected are 7.45–8.15 a.m.; 4.30–5.30 p.m.; 8.15–9.15 a.m. and 3.30–4.30 p m.

In general, the output increases as the proportion of work done under artificial light decreases Thus, the greatest relative increase in successive weeks is in the hours 7.45 to 8.15 a.m. and 4.30 to 5.30 p.m. In the former case there is a noticeable increase after the fifth week, when artificial illumination is no longer used

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[1] A Study of Output in Silk-Weaving during the Winter Months, by P. M. Elton, M Sc (*Ind Fat. Res. Board, Report No* 9).

for the whole period and decreases in duration in the following weeks. From 8.15 to 9.15 a.m. the output begins to increase after the second week up to about the seventh. The output from 9.15 to 10.15 a.m. fails to increase after the fourth week, and from 10.15 to 11.15 a.m. it is only slightly affected by the illumination conditions. In the afternoon spells of work similar tendencies are noticeable. Thus, although the morning or afternoon average efficiencies may be fairly uniform during the weeks when the duration of artificial light is decreasing, the increase in efficiency during the hours most affected may be from 4 to 6 per cent. in favour of natural illumination. The curves also show the effect of differences in natural illumination. A small but distinct rise in efficiency will be noticed for the periods 10.15–11.15 a.m., and 2.30–3.30 p.m., during which no artificial lighting was used. This rise is probably due to the gradually increasing power of daylight between these hours as the days lengthened.

TABLE X.—*Showing hourly variations in efficiency during the first twelve weeks of the year.*

Week	7·45 — 8·15	8·15 — 9·15	9·15 — 10·15	10·15 — 11·15	11·15 — 12·15	Average	Artificial Illumination.
1	80·3	84·6	84·6	86 5	84·6	84·6	63 minutes.
2	80·6	84·1	85·3	86·9	83·9	84·6	65 ,,
3	80·1	84·5	85·8	87·3	83·8	84·8	65 ,,
4	81·0	84·6	88·4	87·5	84·0	85·6	40 ,,
5	80·4	85·1	88·6	87·8	82·6	85·4	39 ,,
6	81·6	87·2	87·7	88 1	81·0	85·5	25 ,,
7	82·8	88·7	88·6	87 9	83·1	86·6	14 ,,
8	81·7	87·7	87·8	87·7	83·0	86·0	6 ,,
9	82·6	87·9	87·6	88·2	82·0	86·0	—
10	85·3	88·4	87·8	88·0	83·8	86·8	—
11	86·3	88·1	87·9	87·8	82·4	86·5	—
12	86·7	87·9	88·0	88·1	82·9	86·7	—

Week.	1·15 — 1·30	1·30 — 2·30	2·30 — 3·30	3·30 — 4·30	4·30 — 5·30	Average	Artificial Illumination.
1	80·4	87·1	86·7	85·6	83·9	85·5	92 minutes
2	80·4	87·4	86·9	86·1	84·6	85·9	89 ,,
3	78 4	85·8	87·4	86·5	83·3	85·4	77 ,,
4	80·8	85 8	87 0	86·3	84·2	85·6	67 ,,
5	78 0	85·1	87·0	86·9	84·4	85·4	34 ,,
6	78·4	85·6	87 2	87·4	85·3	85·9	33 ,,
7	78·8	85·7	87·4	87·8	85·8	86·2	24 ,,
8	79·6	85·3	86·9	87·9	86·4	86 2	16 ,,
9	80·0	85·0	88·8	88·3	87·6	85·7	9 ,,
10	79·6	86·8	87·6	88·0	87·2	87·0	—
11	80·9	86·6	88·4	87·6	86·4	87·1	—
12	80·5	85·9	87·8	87·7	87·0	86·7	—

The above results are further represented in Fig. 15.

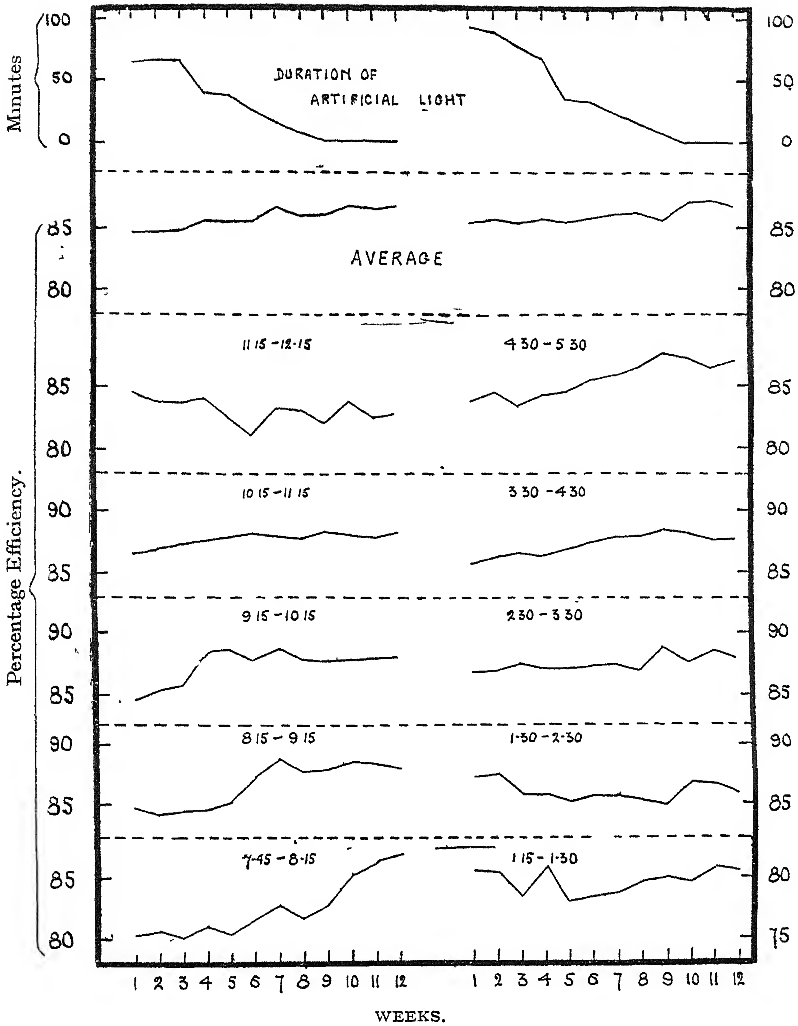

Fig. 15. Effect of Artificial Illumination on Efficiency.

A similar analysis of the results obtained from shed A, in which both the natural and artificial system of illumination were very good, failed to show any definite relation between the kind of illumination and output. This suggests that with suitable arrangements artificial lighting need not necessarily be inferior to natural.

Two-break day.—Some additional information regarding the effects of lighting on output has been obtained from a humid shed (K) in which a two-break day was worked. Results obtained during July and August have been compared with those obtained in October, November, and December.

For most of the latter period artificial light was used during the whole of the first spell, and from 3.30 to 5.30 p.m. in the third spell. The average hourly output during each spell, expressed in terms of the highest average output during any one spell in the same period, is given in Table XI.

TABLE XI.—*Giving comparative output during summer (S) and winter (W) months.*

Spell.	Output		Temperature.		Relative Humidity	
	S	W	S	W	S	W
1	97 3	91·3	62·3	60·1	88·0	84·0
2	99·0	100 0	66·2	64 5	87·0	86·0
3	100·0	93 9	69·3	68·5	85·5	83·5

The results in Table XI, which were obtained from 25 looms, are further represented in Fig. 16.

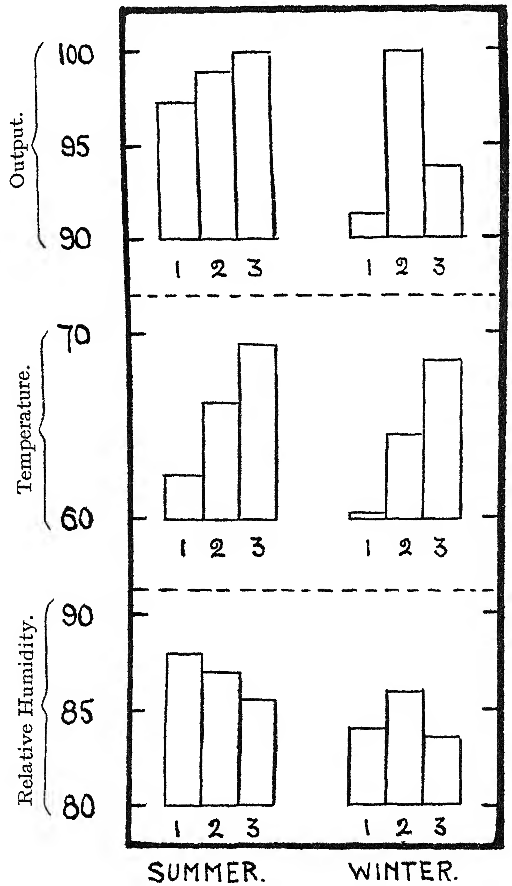

Fig. 16. Comparison of output in Summer and Winter.

Since a slightly different kind of cloth was woven on some looms during the two periods under consideration, the summer and winter efficiencies themselves are not strictly comparable, but the distribution within each period may be justifiably compared. It will be seen that the shapes of the output curves are very different for the two periods. In summer the average hourly output rises in successive spells, but in winter the output during the second spell is much higher than in the preceding and following spells.

It is unlikely that the differences in the output curves are due to temperature differences, for although the average winter temperature is slightly less than that for the summer, the temperature curves for the two periods are similar in shape The relative humidity curves differ chiefly in the portion representing the results obtained in the first spell, and the low output in the first spell during the winter months is probably due partly to the comparatively low relative humidity during that spell.

The chief cause of the decreased output in the first and third spells during the winter months is, however, the effect of working under artificial illumination. The output during the first spell, instead of being 1·7 per cent. less than that of the second spell as in summer, in winter is 8·7 per cent. less. Similarly, that of the third spell is 6·1 per cent. less than the second in winter, but in summer it is 1 per cent. more. Since the output for the second spell in winter would probably be less than the output in the corresponding summer spell (because of the lower temperature and relative humidity in winter), the output values for the first and third spells in winter would be still further reduced if the winter results were expressed according to summer standards.

The results of this investigation show that artificial illumination of the kind observed is inferior to natural illumination in industrial processes such as weaving. Apart from the additional expense involved when artificial light is used, the quantity and quality of the material produced also suffer, and it is probable that such conditions accelerate the onset of fatigue in the operatives. In a shed having a two-break day, artificial light is used for a longer period than in one having a one-break day, so that in this respect the latter distribution of hours has the advantage.

(iii) *Photometer Measurements*.[1]

During the winter of 1920–21, a preliminary study of artificial lighting systems was made in sheds A, B, C, and D. Because of the incomplete nature of the investigation, the results obtained are merely suggestive, but since they possess a certain amount of interest they have been included in this report. The illumination on the warps was determined by means of a photometer. From 20 to 40 observations were made in different positions at different times in each shed, and in every case independent readings were

[1] The writer is indebted to Mr A D Ogden and Mr F. Radford for the results given in this section of the Report.

taken by two investigators. If the difference between the results obtained by the investigators was less than 0·05 foot candle, the average of the two readings was taken; if greater than this value, the observations were repeated until consistent results were obtained.

The results obtained, together with particulars connected with the lighting system in each shed, are given in Table XII.

TABLE XII.—*Giving illumination results obtained in the different sheds.*

Shed.	Type of Illumination	Number of looms per light source.	Average height of light sources.	Reputed Candle Power.	Average Illumination on warp
A	Electric	2	6 ft. 1 in	32	1·50 ± 0 30
B	Incandescent Gas ..	2–6	6 ft. 4 in.	—	1·22 ± 0 30
C	Electric	2	6 ft 2 in.	16–25	1·48 ± 0·34
D	Electric	4	6 ft. 5 in.	50	1·17 ± 0·24

The illumination is fairly similar in the different sheds. During the course of the investigation the opinions of several operatives regarding the lighting arrangements were obtained. In sheds A, B, and C, the conditions seemed to give satisfaction, but in shed D the arrangements were generally condemned. The light on the warps was said to be poor, and complaints about the shadows were received. The greater part of the light was said to shine on the space between the looms, and the tacklers stated that it was difficult to carry out repairs at the end of the loom away from the source of light. In this shed there were four looms to each source, but in the others one source served for two looms. It appears, therefore, that more sources of lower candle power are more efficient than fewer of higher candle power.

The effect of the relatively inadequate lighting system in shed D upon efficiency is seen in the analysis of the output results obtained in that shed. (*See* pp. 22–23.)

(iv) *Glare.*

The efficiency of a lighting system depends not only upon the amount of light it provides, but also upon the manner in which the source is placed. Frequently, misdirected light gives rise to glare, which causes discomfort and probably induces eye-strain. The effort required in the accommodation of the eyes under defective conditions of illumination is conducive to headaches. If the vision is defective and uncorrected by glasses (as is frequently the case), the effects upon the operative are accentuated.

In industrial occupations the chief causes of glare are bright sources of light in the line of vision, light which strikes the eye obliquely, and reflection from brightly polished surfaces. In weaving sheds, conditions of the two former types are common.

The sources in the sheds under consideration were a little over six feet above floor level, and in no case did the reflector on the light obscure more than two-thirds of the globe when the eye was placed on the same level as the lower rim of the reflector. In most cases, therefore, about half the bulb could be seen by the operatives. If the weaver is looking down at the cloth on the loom, then light from the lamps does not strike the eye directly, but otherwise she is exposed to this light. Such conditions are undoubtedly unsatisfactory and conducive to eye-strain and fatigue. They could be improved by using deeper reflectors[1] which would not only eliminate glare but also concentrate the light upon the warp.

Throughout the whole period of artificial illumination, the weaver is exposed to light which strikes the eyes obliquely, and the distracting and disturbing effects of such sources of light are well known. Glare, like noise, is frequently ignored because it is so often with us, and its disadvantages are fully realised only when it is completely removed.

(v) *Shadows.*

Light sources placed in unsuitable positions often cause shadows in places where they are least desired. In this way not only is the practical efficiency of the light decreased, but the mobility of shadows is very disconcerting. Shadows caused by belting were noticeable in some sheds, and these, because of their flickering nature, are particularly troublesome. In sheds containing the individual form of electric drive (*e.g.*, shed A) shadows due to belting are, of course, entirely absent

In shed D the position of the lights sometimes caused a shadow of the weaver to be cast upon the warp when she was attending to breakages, but this was less noticeable in the other sheds.

A large and avoidable shadow was noticed in shed D due to the practice of placing completed cuts on the top of the loom, and a slight but distinct shadow was also caused by the movements of the healds.

B. Personal Factors.

Weaving efficiency is affected by many personal or subjective factors. Only those more intimately connected with factory conditions are discussed in this Report, and some of the most important, such as health, home life, and leisure, are necessarily omitted.

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[1] Since this Report was written, the Second Report of the Departmental Committee on Lighting in Factories and Workshops (Cmd. 1418) has appeared, which recommends that " Every light source (except one of low brightness) within a distance of 100 ft. from any person employed shall be so shaded from such person that no part of the filament, mantle or flame is distinguishable through the shade, unless it be so placed that the angle between the line from the eye to an unshaded part of the source and a horizontal plane is not less than 20°, or in the case of any person employed at a distance of 6 ft. or less from the source, not less than 30°."

(a) Ability.

The existence of individual differences in ability is shown by the fact that the number of ordinary looms weaving the same kind of cloth controlled by one weaver varies from two to five or six. It is quite common for a weaver, when given an additional loom, to give it up after a short trial.

In order to determine the magnitude of individual differences in efficiency, the results obtained from shed D during a typical month in summer have been treated as shown in Table XIII. The operatives concerned were all experienced weavers and had been in the employ of the firm for several years.

Table XIII.—*Showing variations in efficiency on different looms.*

Weaver	Loom No.	Efficiency. Per Loom	Efficiency. Per Weaver	Weaver	Loom No.	Efficiency Per Loom	Efficiency Per Weaver.
A	1 2 3	90·6 91·2 90·2	90·7	H	22 23 24	91·6 92·7 93·3	92·5
B	4 5 6	92·6 91·8 93·5	92·6	I	25 26 27	82·2 83·6 84·5	83·4
C	7 8 9	88·1 81·1 84·1	84·4	J	28 29 30	91·8 89·5 88·3	89·9
D	10 11 12	68·0 73·6 69·1	70·2	K	31 32 33	84·3 83·9 87·0	85·1
E	13 14 15	88·1 88·8 87·4	88·1	L	34 35 36	89·8 88·2 90·1	89·4
F	16 17 18	87·4 92·6 85 1	88 4	M	37 38 39	80·8 84·9 82·1	82·6
G	19 20 21	82·3 80·8 81 4	81·5				

Assuming each weaver gives the same attention to each of her three looms, the efficiency on each should be theoretically the same. Considerable variations exist, however, between the efficiency of the looms in each group of three, and in some cases the difference is as much as 7 per cent. While it is possible that a weaver may have a favourite loom to which she gives special attention, the differences observed are probably also due to objective differences in the yarn or the loom mechanism. When two looms controlled by the same weaver and weaving exactly the same class of cloth give a difference in output of 7 per cent., it is surely time for the management or overseers to find the causes of the differences, and by removing the defects, increase the production on the inefficient loom. Very few managers make

a careful study of the efficiency of each loom, it is only when an obvious decrease in output occurs that attention is aroused. An accurate knowledge of the efficiency of every loom would not only lead to an increased output in the case of defective looms, but would probably result in a discovery which would enable the efficiency of the whole shed to be raised. Even if a weaver has a favourite loom, it is usually because it is mechanically more efficient than the others.

In addition to the individual loom efficiency, the results in Table XIII give the average efficiency for each group of three looms, or the weaver's efficiency. Thus, figures representing individual differences in efficiency vary from 70·2 to 92·6 per cent., a difference of 22·4,[1] while the average deviation from the mean is 4·5 per cent

Since the kind of cloth woven was the same on all the looms, these values are fairly representative of individual differences in weaving ability, and since weaving is to a large extent controlled by the mechanical factor, the differences recorded are large and significant. It is highly probable that the causes of these large differences will be found in individual variations in natural ability and in methods of work. Differences due to the former cause can to a large extent be removed by the application of vocational tests in the selection of workers. Those operatives who fail to show the necessary amount of weaving ability would probably be happier and more profitably employed in some other section of the industry. Differences due to variations in the method of work could be remedied by an improvement in the system of training.

Variations in output which may be attributed to fatigue are much smaller than those due to individual differences in ability.

(*b*) Experience.

This factor is reserved for a later report.

(*c*) Incitement and Practice.

By incitement is meant the improvement in mental and muscular co-ordination which takes place when a process is being resumed after a short break. By practice is meant the acquisition of skill by the worker in becoming expert.

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[1] In silk weaving, Elton found that in one quality of cloth the efficiency of different weavers varied from 55·0 to 82·2 per cent, and in another class from 39·2 to 70·6 per cent. These differences are much larger than those observed in the cotton industry, and indicate the greater difficulty of silk weaving and its greater dependence upon the human factor The same investigator even states that "the *whole* question of production in power-loom weaving is dependent on the abilities of the weaver." This statement seems to be somewhat inaccurate, because in the same report (page 15) he shows how the rate of production may be affected by a change in the raw material, and in another case (Report No 9, p 55, of the Industrial Fatigue Research Board) dependence of production in silk weaving upon temperature has been demonstrated

During short intervals between work the human machine grows "cold," and requires "warming-up" before the stage of maximum efficiency is reached. In the present investigation the effect of this factor of incitement is seen in the low efficiency at the beginning of the spells of work although the results are somewhat complicated by irregularities in the time of starting work and the lower temperature and humidity which prevail at that time. In general, the efficiency usually increases during the first three to three and a half hours of work (*see* Figs 6, 7, and 8), rapidly at first but more slowly afterwards, and then decreases until the cessation of work at 12.15. The efficiency immediately following the resumption of work at 1.15 is comparatively low, but increases rapidly to a maximum and afterwards falls until work ceases at 5.30 (*see* Fig. 6).

The shape of the work curve is usually explained in terms of subjective factors such as practice, incitement, and fatigue. Thus the comparatively low efficiency at the beginning of each spell is generally attributed to loss of swing or incitement caused by the preceding break, and the subsequent increase in efficiency is said to be due to improved attention and muscular co-ordination as the recovery from loss of swing proceeds. Once the highest point of muscular co-ordination and activity is reached, the efficiency usually remains at that level until the effects of fatigue become noticeable, when the curve falls until work ceases. Occasionally a rise in the curve occurs just before the cessation of work; a phenomenon which is said to be due to a "final spurt" caused by the knowledge that the end of work is near, which acts as a temporary incentive to greater effort. This final spurt was very noticeable in shed A, but does not appear in the curves, since it is masked by the average efficiency taken over a whole hour. Under industrial conditions the work curve is frequently modified by factors connected with local conditions of work, and the results of this investigation are not free from these disturbing influences. In this inquiry, it must be remembered that a rise or fall in the curve does not necessarily indicate a corresponding increase or decrease in human efficiency, but may be due to favourable or unfavourable atmospheric conditions in the shed acting upon the material used in the manufacturing process. The results given above accordingly represent the resultant effects of the conditions of work upon the operatives and upon the yarn used in the weaving process.

In cotton weaving one might expect to find human efficiency at its maximum shortly after work has begun, consequently in the morning spells some disturbing factors are evidently at work. The atmospheric conditions in the sheds at the beginning of the morning spells, particularly in winter, are unfavourable to efficient weaving and some time elapses before the most favourable atmospheric conditions are attained. Probably, also, the yarn does not respond immediately to variations in the temperature and humidity of the air, for these physical factors act first upon

the surface of the yarn and require time before their effects penetrate into the interior. These comparatively unfavourable conditions operating from the beginning of work in the morning spells cause an increase in the number of yarn breakages, and although the weaver may be working more efficiently at 9.0 a.m. than at 11 0 a.m. the greater number of breakages at the earlier hour may account for the lower weaving efficiency which then occurs.

When work is resumed at 1 15 the conditions of temperature and humidity in the sheds are favourable to production and consequently differ in this respect from those which prevail during the early stages of the morning spell. The almost immediate realisation of maximum efficiency during the afternoon spells suggests that the recovery from loss of swing caused by the dinner hour interval is very rapid, but in many cases this level of efficiency is not maintained. The subsequent decrease in efficiency is probably due almost entirely to the effects of fatigue, and during the winter months to the use of artificial light.

On Monday morning the initial efficiency is usually less than at any other time during the week. The low efficiency on Monday morning is due to the effect of the week-end break upon the operatives and upon the material used in weaving. In the case of the operatives there is usually a general disinclination to resume work on Monday morning, and the week-end break causes a loss of incitement and of some practice in the activities involved in the weaving process. During the same period the machinery is idle and the warp exposed to unfavourable atmospheric conditions, with the result that when work is resumed on Monday morning the machinery is a little "stiff" after the week-end "rest" and the yarn is less humid and at a lower temperature than on other mornings in the week.

Similar conditions prevail when work is resumed after a holiday and the effect usually extends over a few days. In general, the longer the interval between the periods of work, the greater the effect of loss of practice.

(*d*) Incentives.

Since all the operatives included in this investigation were paid on a piece-rate basis, the effect of different methods of payment upon efficiency could not be determined, but it is generally agreed that a piece-rate is much more satisfactory than a time-rate. The method of payment adopted, however, shows the effects of the "booking-up" incentive.

(i) *Booking-up.*

In the humid sheds containing ordinary looms the weekly wage received by a weaver depends upon the number of cuts completed at a certain time during the week. Since an unfinished cut is

carried forward to the next week, additional effort is expended upon those cuts which can be finished before booking-up time arrives. The time varies in the different sheds and the method of procedure is also different. In some sheds the weavers take the completed cuts to the warehouse to be booked, but in others a clerk visits each loom for the same purpose. In every case the approach of the booking-up period acts as an additional incentive to work, and usually the efficiency begins to increase some time prior to this period.

In sheds A and B booking-up takes place on Wednesday morning, in shed C on Friday afternoon, in sheds D and E on Tuesday morning, and in shed H on Tuesday afternoon (*see* Fig. 5). At the time of booking-up, work is frequently interrupted by the absence of the weavers from their looms, and on the following day there is usually a decreased efficiency due to a general relaxation of effort following the booking-up process. The desire to increase the weekly wage has been temporarily realised and the stimulus to increased activity no longer exists.

When booking-up occurs on Wednesday morning (sheds A and B), the usually high efficiency attained on Tuesday tends to be still further increased by the effect of the booking-up incentive. General principles suggest that favourable incentives should operate when they are most needed, and the best time for booking-up is probably Saturday morning, since the work on that morning is also disturbed by the cleaning and sweeping of looms.

The system of booking-up has also an effect upon weaving efficiency. In some sheds the weavers take the completed cuts to the warehouse to be booked, and consequently are away from their looms for an appreciable time. In others the tacklers visit the looms for the purpose of booking the cuts, and the time lost in this case is not so great.

In sheds F and G, containing automatic looms, the booking-up process takes place on Wednesday morning, but because of the system adopted the effect is not so marked, and accordingly differs from that observed in connection with ordinary looms. In sheds F and G pick recorders are fixed to all looms, and when work is finished on Wednesday morning, readings are taken from these instruments and the weekly output on each loom thereby obtained. Since incomplete cuts are included in these readings, the desire to finish a cut before booking-up time arrives does not exist, and the incentive found to be effective in the other sheds is absent in sheds F and G.

(ii) *Holidays.*

The effect of the holiday incentive upon output is seen in the weeks immediately preceding the holidays. The greatest effect is seen in the second week before the holidays (*see* Fig. 1). In the electrically-driven sheds it is quite common for the fuses to burn out during this period of increased output because of the increase

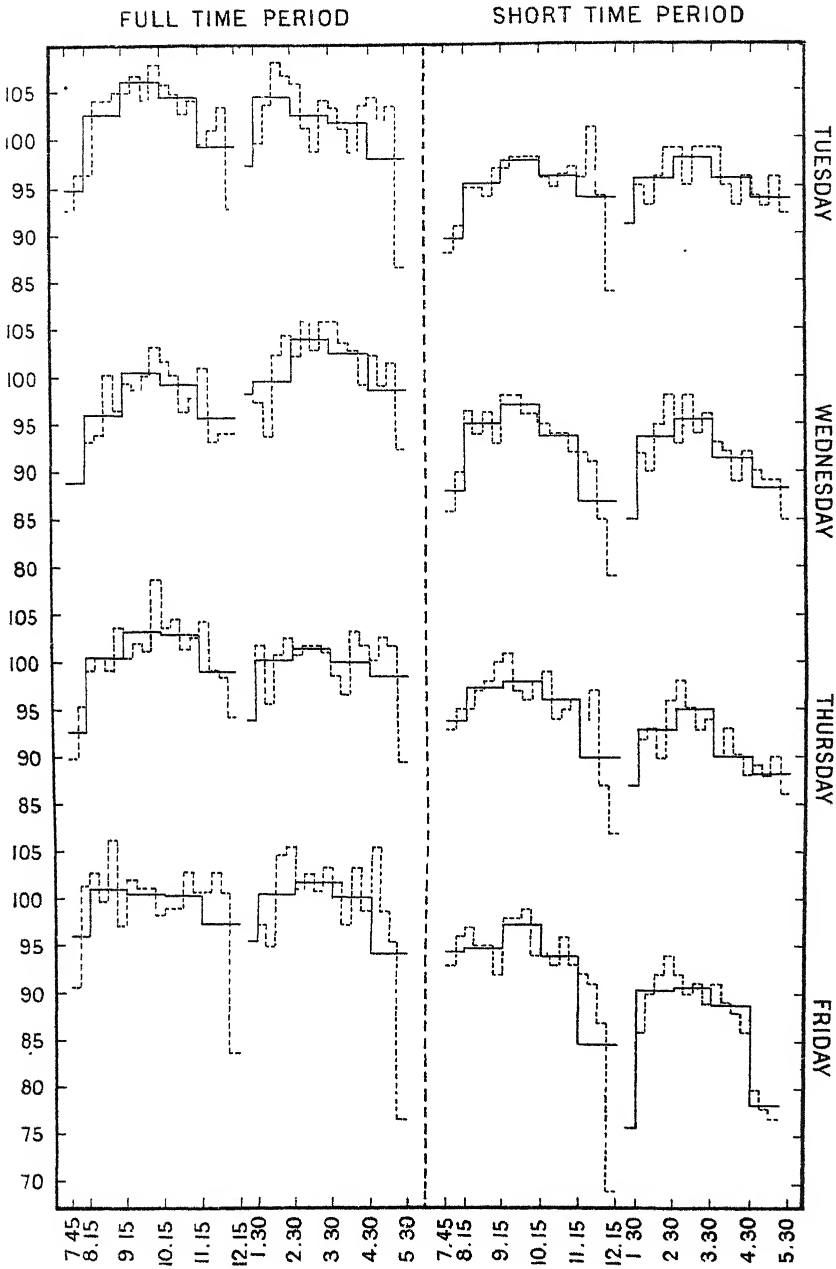

FIG.17. HOURLY VARIATIONS IN OUTPUT IN FULL AND SHORT TIME PERIODS (SHED H.)

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the holidays contains days which, for the purpose of wage payments, are carried over to the week following the holidays, consequently the output on these days is less than usual and the weekly average is lowered.

The increase in the weeks immediately preceding the Easter and Whitsuntide holidays is not so well marked as is the case of the annual holidays, because the latter are longer and recognised as the chief holidays of the year, in which money is freely spent (*see* Fig. 1).

The " holiday spurt " suggests that the operatives possess a reserve of energy which can be liberated under the influence of suitable incentives. Presumably a slower rhythm or speed of work is found to be more suitable under normal conditions, and the increased efficiency before the holidays represents a temporary spurt which could not be maintained through the year. In this respect the situation is analogous to the behaviour of the long-distance runner who maintains a fairly constant speed over the greater part of the course, but " goes all out " when approaching the goal.

(iii) *Short Time.*

During the latter part of this investigation the cotton industry began to suffer from the effects of bad trade. In some cases short time was worked, but in others the sheds were closed. In shed H the operatives worked from Tuesday to Friday (four days) for a period of nine weeks, and the results obtained have been compared with those observed when full time was worked.

The average hourly output during the short time period was 370 units, as compared with 394 units when full time was worked under similar atmospheric shed conditions. The hourly variations in output during these two periods are given in Fig. 17.

Thus, the output during the short time period is a little over 6 per cent. less than that when full time is worked, and since the atmospheric conditions in the shed were practically the same during the two periods, the difference in output must be attributed to the psychological effect of short time upon the operatives.

The curves representing the hourly variations in output are not only on a lower level during the short time period, but in the latter part of the week the fall in output during the second half of the morning spell is much greater than in the normal curves. The afternoon curves, instead of remaining equal to or being higher than the morning curves, show a progressive decrease in output as the week proceeds. Thus, short time of the nature under consideration has a most unfavourable effect upon rate of working ; a result which appears to be due almost entirely to the modified attitude of the operatives towards their work. Even at the beginning of the week the operatives are not working at their usual speed, and the rate is still further reduced as the week advances. The decreased working capacity of the operatives may be partly due to the disturbing effects of short time, which interferes

with their usual habits and desires, but it may also represent a restriction of output caused by knowledge of the limited amount of work available, and a consequent attempt to postpone the advent of further unemployment. The fear of unemployment is always an obstacle to efficiency, and unless it can be entirely removed, maximum efficiency will never be attained.

(*e*) Fatigue.

In the weaving process variations in the working capacity of the operatives are inadequately expressed by efficiency percentages, because of the overwhelming effect of the mechanical factor Thus an efficiency of 90 per cent. means that the looms are running for 54 minutes in the hour, and during that time production is not appreciably dependent upon the degree of fitness or fatiguability of the operative. The working capacity of the operative is reflected in efficiency percentages only when she is attending to loom stoppages, and in the case of an efficiency of 90 per cent. the duration of these will be only six minutes in the hour. If, in another hour, the efficiency falls to 89 per cent., the time taken to repair breakages is now 6·6 minutes. Thus, although the decrease in productive efficiency is only 1 per cent., the operations performed by the weaver have increased in duration from 6 to 6·6 minutes, or by 10 per cent. In other words, a decrease in human efficiency of 10 per cent., when the original efficiency is 90 per cent., is shown in efficiency percentages by a decrease of only 1 per cent.

Incidentally, this method of treatment enables variations in efficiency in a semi-automatic process, such as weaving, to be put on a comparative basis either with handwork or with other partially automatic processes. If decreases in efficiency are due chiefly to the effects of fatigue, it is possible to transform small variations in efficiency in highly mechanical operations into significant expressions of fatigue. This method of treatment has been applied to the records obtained from shed B, because of their greater regularity and continuity.

(i) *Daily variations.*

It has been assumed that the working capacity of the operatives is at a maximum on Tuesday mornings, and the efficiency obtained at other times during the week is expressed in terms of the efficiency, which would have been observed if the work had been done on Tuesday morning under the same conditions of temperature and humidity. Thus, suppose the average Thursday afternoon efficiency is found to be 88·2 per cent., while that on Tuesday mornings, having the same temperature and humidity, is 89·0 per cent. In the latter case, the time taken to attend to loom stoppages is 11·0 per cent, but in the former it is 11·8 per cent. Thus, stoppages which on Tuesday mornings take the weaver 6·60 minutes every hour to overcome, on Thursday afternoon require 7·08 minutes: an increase of 7·3 per cent. In other words, the

working capacity of the weaver on Thursday afternoon is 7·3 per cent. less than it would have been under the same conditions on Tuesday morning, although the output only falls from 89·0 to 88·2 per cent. In the same way, the percentage increase in the time taken by the weaver at other times during the week in attending to loom stoppages has been determined, and the results are given in Table XIV.

TABLE XIV.—*Showing percentage decreases from the maximum working capacity during the morning and afternoon spells.*

	Mon.	Tues	Wed	Thurs	Fri. .
Morning . .	1·6	0·0	1·1	1·5	2·3
Afternoon . .	5·5	6·2	6·3	6·7	7·5

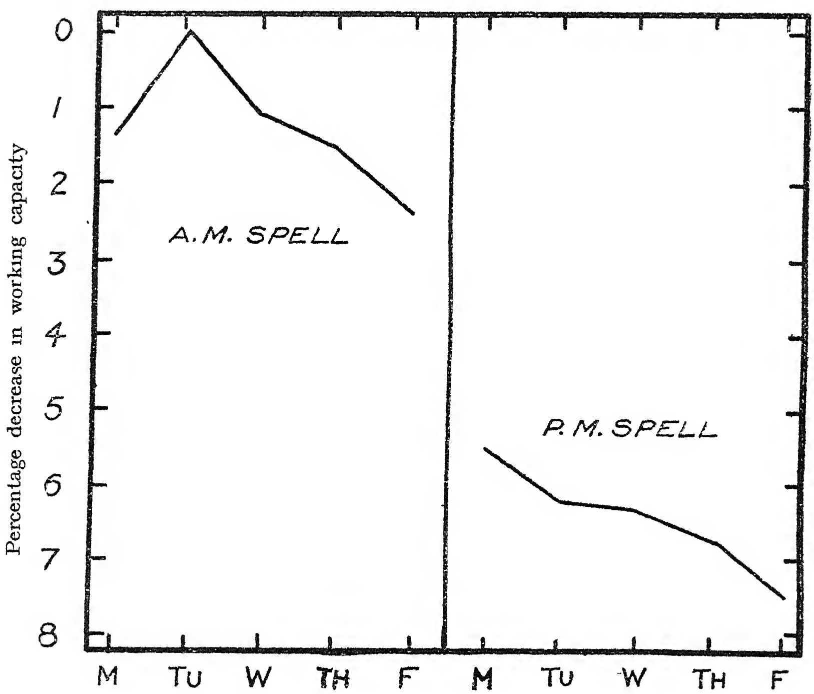

Fig. 18. Daily variations in working capacity.

The results, which are also represented in Fig. 18, show that the time required to attend to loom stoppages is greater in the afternoon than in the morning spells of work, and increases in each successive morning (except Monday and Tuesday) and afternoon spell, until on Friday afternoon it is 7·5 per cent. greater than it would have been under similar atmospheric shed conditions on a

Tuesday morning. Such results are suggestive, and indicate a progressive decrease in the working capacity of the operatives as the week proceeds. The most probable reason for this decrease is the cumulative effects of fatigue caused by the incomplete recovery during the night from fatigue produced in the course of the day's work, except on Monday morning, when it must be attributed to the "Monday effect," which has already been discussed. This method of presenting the results as a percentage increase in the time required to perform a given task gives a more representative value to human variations in efficiency.

(ii) *Hourly variations during a composite day*

In this case it has been assumed that the working capacity of the operatives is at a maximum from 8.15 to 10.15 a.m., and the efficiency at other hours has been expressed in terms of the 8.15 to 10.15 a.m. efficiency under the same conditions of temperature and humidity. The decrease in efficiency has been expressed as a percentage of the efficiency which would have been obtained if the work had been done under the same atmospheric conditions from 8.15 to 10.15.

TABLE XV.—*Showing percentage decreases from the maximum working capacity during a composite day*

Time	8·15 – 9·15	9·15 – 10·15	10·15 – 11·15	11·15 – 12·15	1·30 – 2·30	2·30 – 3·30	3·30 – 4·30	4·30 – 5·30
Percentage decrease in working capacity ..	0·0	0·0	1·0	4·8	0·0	5·1	7·2	12·7

The incomplete hours at the beginning of the morning and afternoon spells have been omitted from the table because they are affected by lateness in starting work.

The above results are also represented in Fig. 19, and show that the time taken to attend to loom stoppages increases during the last two hours of work in the morning spell; falls to the minimum level from 1.30 to 2.30 p.m., but afterwards rapidly increases until work ceases at 5.30 p.m. In the last hour of the afternoon spell the working capacity of the operatives is 12·7 per cent. less than at 8.15 to 10.15. Since these results are independent of the effect of variations in the atmospheric shed conditions upon the yarn, they represent changes in the working capacity of the operatives which are due almost entirely to the effects of fatigue. They accordingly indicate the relative effects of the accumulated fatigue during the course of the working day.

It appears that the dinner hour interval is sufficient to dispel the fatigue produced during the morning spell of work, but the effects of fatigue appear earlier and are much greater in the

afternoon than in the morning. The results indicate the extent of the decrease on output which might be expected if weaving were a purely manual instead of a predominantly mechanical operation

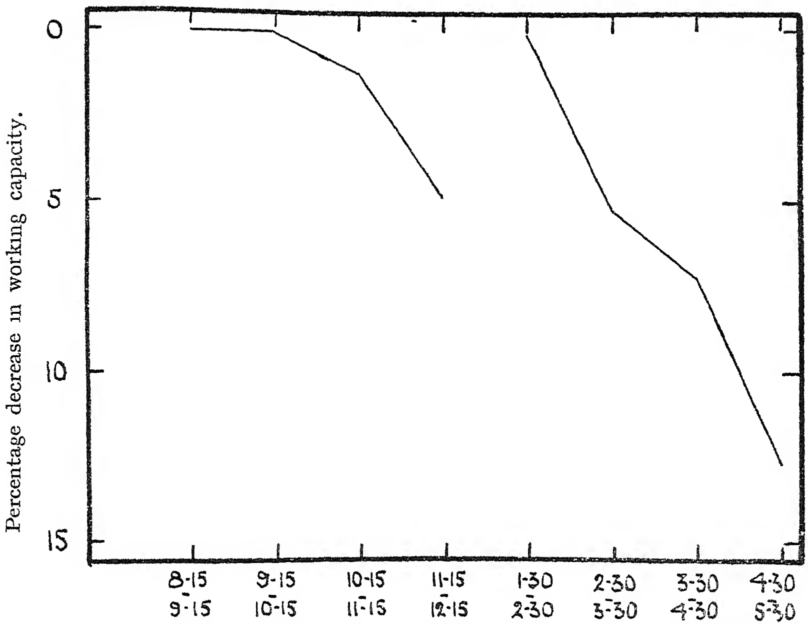

Fig. 19 Hourly variations in working capacity (typical day).

(iii) *Hourly variations during a typical week.*

The results given in this connection are based upon the assumption that the operatives are most efficient from 8.15 to 10.15 a.m. on Tuesday morning. The actual efficiency obtained at any other time during the week has again been converted into the equivalent Tuesday morning efficiency, and the differences between the actual and possible efficiencies expressed as percentages of the normal time taken to attend to loom stoppages. These percentages are given in Table XVI and Fig. 20.

TABLE XVI.—*Showing percentage decreases in working capacity during a typical week.*

	8.15 – 9 15	9 15 – 10 15	10 15 – 11 15	11.15 – 12.15	Avg.	1 30 – 2.30	2 30 – 3 30	3 30 – 4 30	4.30 – 5 30	Avg.
Mon.	1·6	0·9	1·1	2·8	**1 6**	0·0	4·8	6·5	11·8	**5·8**
Tues.	0·0	0·0	0·8	2·9	**0·9**	0·2	5 6	6·9	12·9	**6·4**
Wed.	0 6	0·8	1·6	4·2	**1·8**	0·6	4·9	7·4	12·7	**6·4**
Thurs	0·5	0·9	1·4	5·9	**2·2**	0·4	5·4	7·2	13·8	**6·7**
Fri.	0·8	1·2	2 0	6·3	**2·6**	0·9	6·0	8·1	15·0	**7·5**

As might be expected, the curves representing the results for each day of the week are generally similar to the curve for the composite day, and the remarks made in connection with the latter curves are also applicable here. The above curves, however, indicate the extent of the "Monday effect," and, in addition, show the gradual increase in the time taken to attend to loom stoppages as the week proceeds.

It should be remembered that the method of treatment of the results in this section of the report does not ensure absolute accuracy, but only a degree of probability. In some cases the temperature and relative humidity observed at a particular time during the week occurred only once or twice during the chosen period of maximum efficiency on Tuesday mornings and the reliability of the converted results was accordingly decreased. In most cases, however, the atmospheric conditions observed in the shed at any time during the week also existed on several Tuesday mornings, and it seems highly probable that the results presented in the foregoing pages are approximately correct.

Although the foregoing results show that considerable variations in working capacity exist, it must be remembered that these have very little effect upon efficiency of production, because they can only be reflected in the results during the few minutes in each hour when the looms are stopped. They are, however, important, because they provide a basis of comparison with other occupations.

(iv) *Other indications.*

Other indications of fatigue have also been disclosed in the course of the investigations, as follows :—

(*a*) The progressive change in the shape and direction of the morning curves during the course of the week. In the case of shed C (Fig. 21), the hourly efficiency on Monday morning in winter continues to increase until work ceases at 12.15 p.m., but on Friday morning the maximum point is reached almost immediately and the efficiency then decreases until the end of the spell.

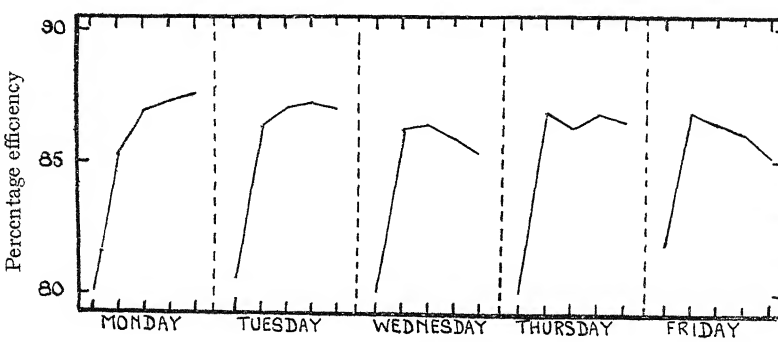

Fig. 21.—Variations in efficiency during the morning spells (shed C).

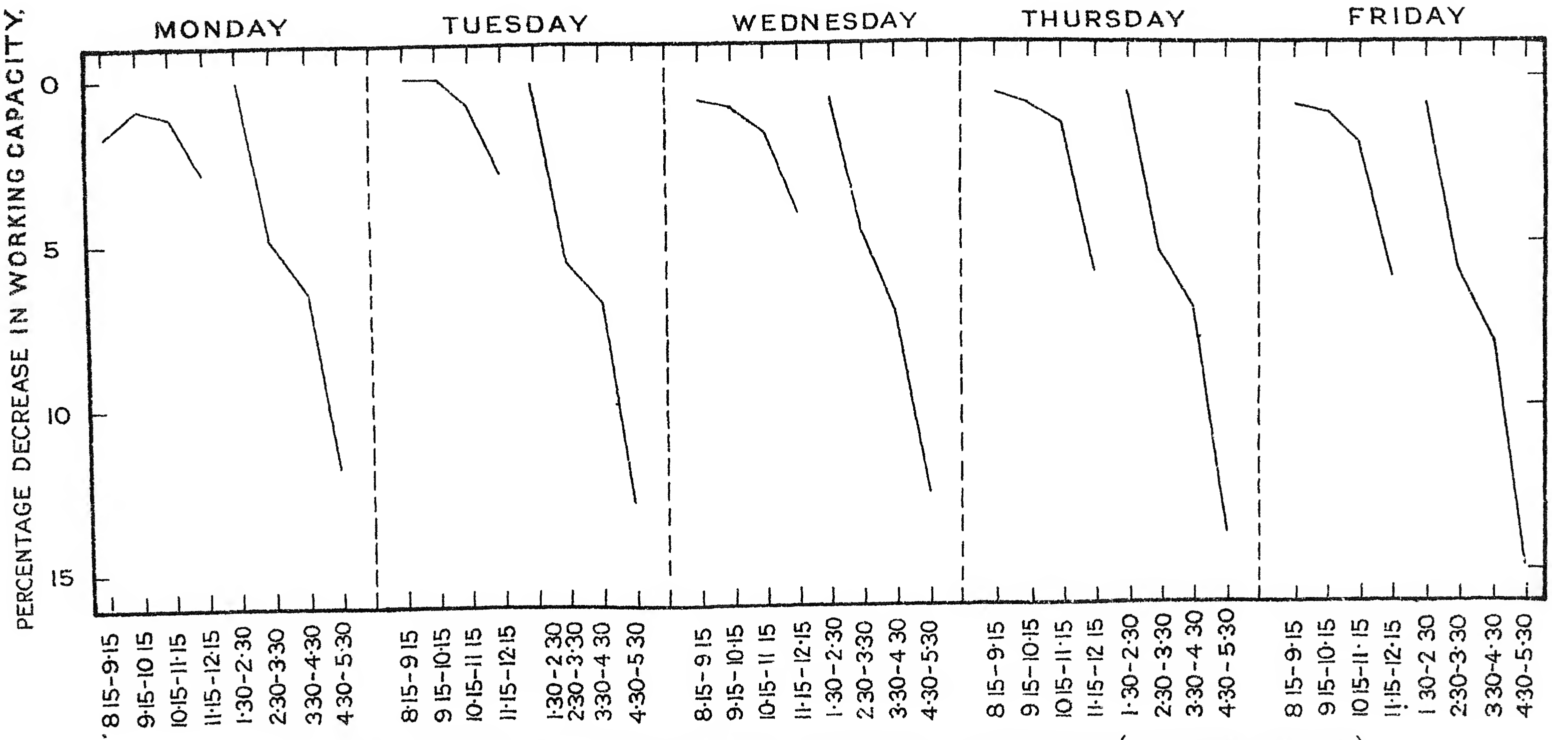

FIG. 20.– HOURLY VARIATIONS IN WORKING CAPACITY (TYPICAL WEEK)

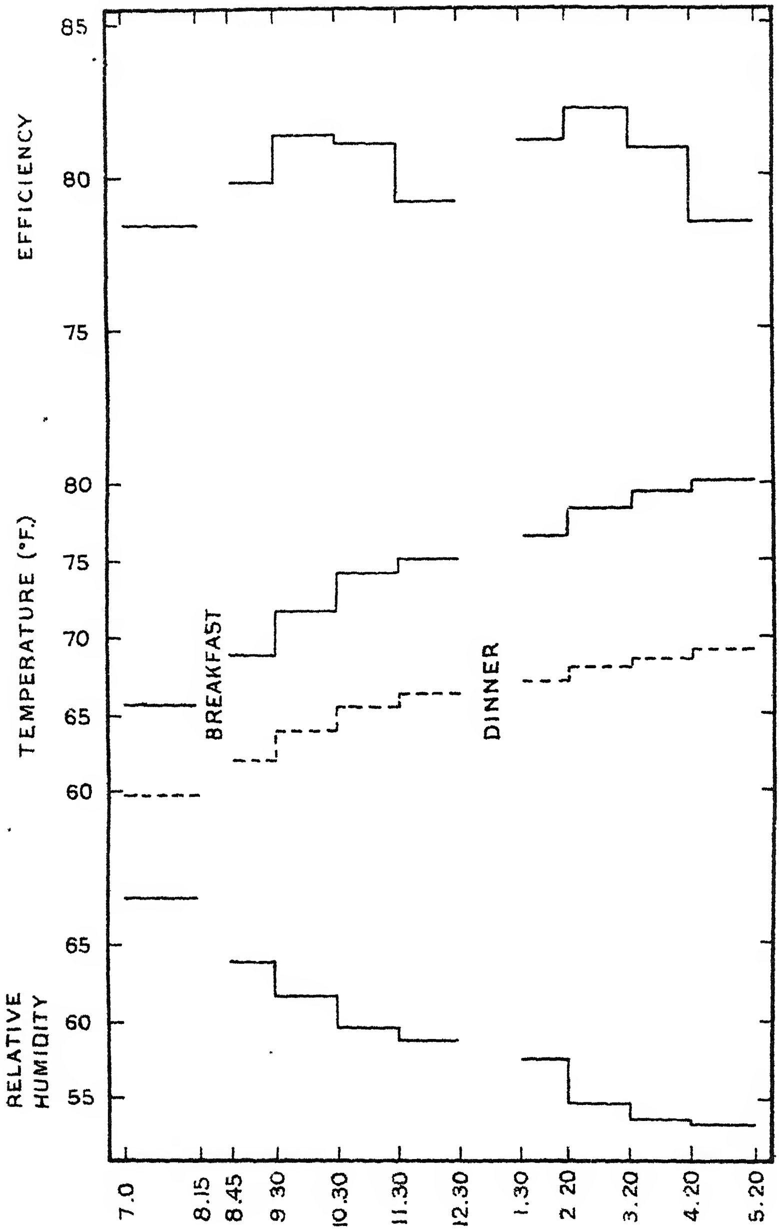

FIG. 22.-HOURLY VARIATIONS IN EFFICIENCY, TEMPERATURE AND RELATIVE HUMIDITY DURING A COMPOSITE DAY IN SUMMER (SHED J.)

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Thus the point of maximum efficiency tends to move from the end of the morning spell on Monday to the beginning of the spell on Friday, and occupies intermediate positions on the other mornings of the week. The gradual transition is not perfect because of the effect of temporary disturbances at different times during the week, but the general tendency is distinctly noticeable.

These facts are most easily explained in terms of fatigue, since they are precisely the conditions which would exist if the operative became fatigued a little earlier on each successive morning of the week. The results also imply an accumulation of fatigue as the week progresses, for although the operative begins work each morning with a fairly constant degree of efficiency, she is unable to maintain a uniform rate of output throughout each successive morning.

(*b*) In shed J, the decrease in efficiency during the latter part of the second and third spells (*see* Fig. 22) is largely due to the effects of fatigue. The greater decrease in the afternoon, as compared with the morning spell, indicates the greater fatiguability of the operatives in the former spell.

(*c*) In shed H, it appears that the decrease in output recorded towards the end of the morning and afternoon spells (*see* Fig. 8) is due to a reduction in the working capacity of the operatives caused by the effects of fatigue. During the last hour of work the output is approximately 10 per cent. less than that for the best hour of the day. Hence, in this shed variations in output during a composite day are much greater than the corresponding variations observed in humid sheds weaving plain cloth, and the difference is probably due to the fact that in shed H fancy fabrics are woven which require more attention and activity on the part of the operatives Thus work in the latter shed appears to be more fatiguing than work in the sheds previously considered.

Since the curves represent results obtained at intervals of 15 minutes, the variations in output which take place during the last hour of the working spell can be traced. It is often thought that the low output observed during this hour is due to the weavers' preparations for departure during the last few minutes. The results show that although a considerable decrease occurs during the last quarter hour, the decrease is by no means confined to this period, but progressively increases throughout the whole hour.

(*d*) The decrease in efficiency which usually occurs towards the end of the morning spell (*see* Fig. 6) suggests that the effects of fatigue become distinctly noticeable after three to three and a half hours' work, for it is difficult to attribute this decrease to anything but exposure to shed conditions and the work already done.

That it is not due to a relaxation of effort caused by the approach of the dinner hour is indicated by the fact that the decrease tends to become more marked towards the end of the week.

Thus even on Monday morning, the improvement due to practice and the recuperative effects of the week-end break are frequently more than neutralised by the effects of fatigue before the end of the morning spell is reached (*see* Figs. 7 and 8).

(*e*) There is a tendency for the curves to fall off more rapidly in summer than in winter. This suggests that the conditions of work in summer are more fatiguing than in winter. The effects are illustrated in Fig. 23, giving the composite curves for the morning spells in summer and winter (shed C).

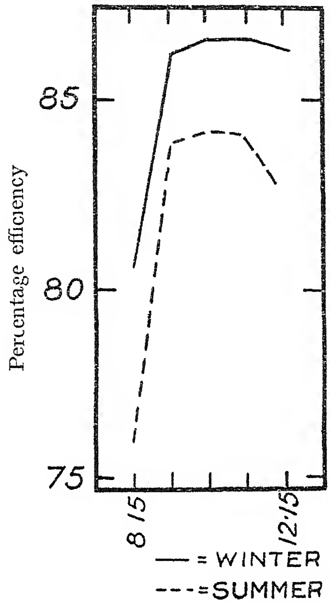

Fig. 23.—Variations in efficiency in Summer and Winter (morning spells).

(*f*) In shed F there is a slight tendency for the daily efficiency to decrease during the week in summer, but not in winter, indicating that the conditions of work in summer appear to be a little more fatiguing than in winter. In shed G, the efficiency in both summer and winter tends to decrease from Tuesday onwards (*see* Fig. 24).

Thus work in the latter shed seems to be more fatiguing than in the former; a result which is probably connected with the higher temperature and humidity, and the greater number of looms per weaver in shed G.

(*g*) The efficiency of shed C in summer is 3 per cent. less than in winter (*see* Fig. 1). This was the hottest shed, and the higher summer temperature, although favourable to the warp, seems to have an adverse effect upon the working capacity of the weavers. In shed B also (*see* Fig. 1), which has the next highest summer temperature, the summer efficiency is only 1·1 per cent. greater than that of winter, yet the summer temperature exceeds the winter by 8·6 degrees, and the relative humidity is only 1·7 per cent. lower in summer than in winter (*see* Fig. 1).

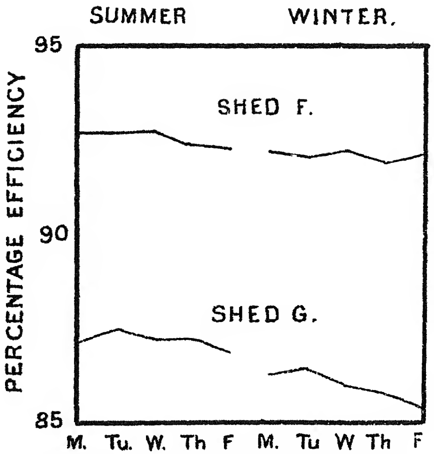

FIG.24. DAILY VARIATIONS IN SUMMER AND WINTER.

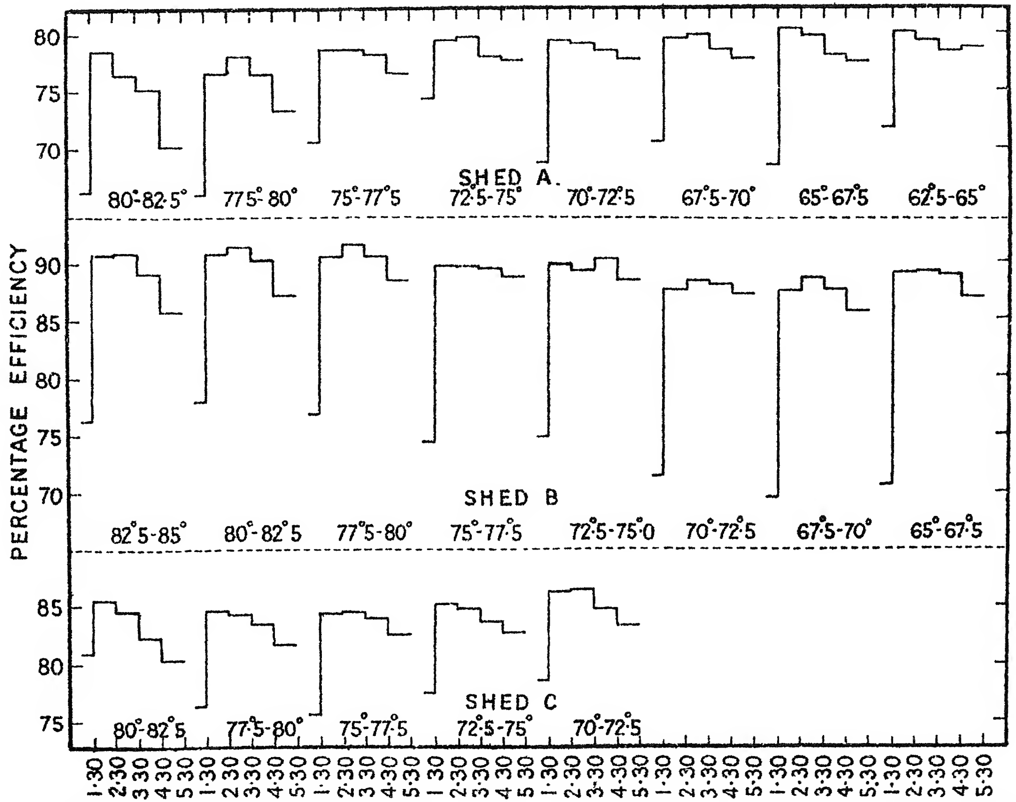

FIG.25. RELATION BETWEEN HOURLY VARIATIONS IN EFFICIENCY & TEMPERATURE

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Although the yarn in humid sheds seems to be favourably affected by an increase in temperature or relative humidity, the actual efficiency of production does not continue to increase indefinitely as the temperature or humidity increases. The number of yarn breakages may continue to decrease, but the ability of the weaver to attend to these breakages seems to be reduced. In other words, the efficiency of the operative is impaired when the temperature and humidity exceed certain limits. This is shown by the following results :—

(i) In shed A, when the temperature was 76·5° and the relative humidity 85·0 per cent., the operatives complained about the heat, and frequently asked about the temperature. When the temperature was 71·7° and the humidity 86·0 per cent., the conditions were considered fairly satisfactory. In the former case the efficiency was 76·5 per cent., but in the latter it was 78·2 per cent., although the temperature was much lower.

(ii) In sheds A, B, and C, the hourly averages for the afternoon spells of work have been arranged according to temperature, and the results are given in Table XVII.

TABLE XVII.—*Showing relation between hourly variations in efficiency, temperature, and humidity.* (*Afternoon spells.*)

Shed	No of Spells	Efficiency 1.15–1.30	1.30–2.30	2.30–3.30	3.30–4.30	4.30–5.30	Average Dry Bulb. (° F.)	Average Relative Humidity.
A	2	66·1	78·6	76·5	75·2	70·2	80·0–82·5	70·1
	8	66·0	76·7	78·1	76·6	73·4	77·5–80·0	75·1
	16	70·6	78·7	78·7	78·3	76·5	75·0–77·5	77·5
	13	74·3	79·4	79·8	78·0	77·7	72·5–75·0	79·7
	12	68·8	79·4	79·1	78·4	77·8	70·0–72·5	82·1
	10	70·6	79·6	79·9	78·6	77·9	67·5–70·0	83·1
	2	68·5	80·3	79·8	78·0	77·5	65·0–67·5	82·5
	3	71·9	80·0	79·3	78·4	78·8	62·5–65·0	82·0
B	2	76·3	90·8	90·9	89·1	85·8	82·5–85·0	71·2
	12	78·0	90·8	91·4	90·2	87·2	80·0–82·5	76·0
	25	76·9	90·4	91·5	90·4	88·4	77·5–80·0	83·0
	33	74·5	89·8	89·7	89·5	88·9	75·0–77·5	79·7
	10	74·8	89·8	89·3	90·2	88·5	72·5–75·0	76·0
	15	71·3	87·7	88·5	88·1	87·2	70·0–72·5	80·0
	7	69·5	87·5	88·7	87·7	85·9	67·5–70·0	82·5
	1	70·5	89·1	89·2	89·0	87·0	65·0–67·5	85·5
C	5	81·0	85·6	84·7	82·4	80·4	80·0–82·5	67·1
	36	76·3	84·7	84·4	83·6	81·8	77·5–80·0	70·2
	33	75·6	84·4	84·5	84·0	82·6	75·0–77·5	71·4
	17	77·3	85·1	84·9	83·8	82·8	72·5–75·0	76·4
	2	78·6	86·2	86·3	84·8	83·4	70·0–72·5	81·5

The general tendency of the above results is seen more clearly in Fig. 25.

The results show that for higher temperatures the decrease in efficiency during the afternoon is, in general, greater than for lower temperatures This is not due to humidity because the curves for the latter factor follow the same direction in each case. This apparent contradiction to the deduction made on p. 13, that rise and fall of output follows the rise and fall of temperature, may be due to the opposite effects of the atmospheric conditions on the weaver and on the yarn, and suggests, that although the number of breakages may be less at the higher temperatures and humidities, the work under such conditions is more fatiguing to the weaver, and the combined effect may sometimes lead to reduced efficiency.

(iii) In shed G there is a gradual decrease in efficiency from week 38 to week 44, although there is a gradual rise in temperature, and to a less extent in relative humidity (*see* Fig. 3). Thus the yarn is exposed to increasingly favourable atmospheric conditions, and yet efficiency progressively decreases. Probably, therefore, the high temperature and humidity during this period, although they cause a decrease in the number of yarn breakages, act unfavourably upon the operatives with the result that the reduced working capacity more than neutralises the improved condition of the yarn.

(iv) Although the number of warp breakages per hour in shed F (3·8) is greater than in shed G (2·6) (*see* Table XXII, p. 46), the average efficiency in the former shed (92·2 per cent.) is higher than in the latter (86·6 per cent.). The difference in efficiency is partly due to the different number of looms controlled by the weavers in the two sheds, viz , 20 in shed F and 24 in shed G, but may also be connected with the much higher temperature and humidity in shed G, causing a reduction in the working capacity of the operatives in that shed. Thus the total number of warp breakages per hour on 20 looms in shed F is 76, while the corresponding number on 24 looms in shed G is 62·4. In the former shed the lost efficiency is 7·8 per cent., but in the latter, with a smaller number of breakages per weaver, it is 13·4 per cent. It seems highly probable, therefore, that the greater loss in efficiency in shed G is due to the adverse effect of the atmospheric conditions upon the operatives, and indicates the futility of exposing the operatives to very high temperatures and humidities.

C. Physical Factors.

(*a*) Yarn Variations.

The efficiency of the weaving process is also directly dependent upon the existence of factors other than temperature and humidity. Of these, variations in the quality of the yarn and inequalities due to sizing are probably the most important.

Although every effort is made in the preliminary operations to reduce the extent of the irregularities in the raw cotton, the result is only partially successful. Since weaving is the last important process in the manufacture of cloth, the yarn used is at the mercy of all the preceding operations and consequently every single thread of yarn contains parts which are weaker than others.

Evidence in this connection has been obtained from observations on warp breakages in shed C. The results in question are given in Table XIX, and represent the number of warp breakages observed on the same warp on different days, together with the corresponding temperatures and humidities.

TABLE XIX.—*Showing variations in the number of warp breakages.*

Date.	Temperature	Relative Humidity.	No of Breakages
1 12 20	70 4	79·9	19
2 12 20	71 0	79·7	12
3 12 20	69 3	78·4	12
7 12 20	67·5	73·8	15
8.12 20	68·9	75·8	24
9 12 20	69·0	83·1	20
10 12 20	71·6	79·3	16
14 12 20	67 8	83·9	28
15 12 20	70·4	76·5	23
16 12.20	70·8	79 8	26
17 12 20	72·1	74·3	50
21 12 20	69·8	73·1	76

Within the small range of temperature and humidity observed, variations in the number of warp breakages are very considerable. It is by no means uncommon to find that variations in efficiency due to the nature of the warp at times greatly exceed those due to differences in temperature or humidity.

In this shed four looms were kept under observation for a period of two and a half months. During that time the number of warp breakages on each loom was recorded, together with hourly readings of the wet and dry bulb thermometers. For statistical purposes only the records obtained from 8.15–11.15 a.m. and from 1.30–4.30 p.m. were used, so that the irregularities connected with the starting and stopping of work were avoided. The results were divided into hourly periods and the degree of correlation between temperature and breakages and humidity and breakages determined. Each correlation series included 282 hourly observations, and the correlation coefficient (*r*) for each pair of variables is given in Table XX.

TABLE XX.—*Giving total correlation coefficients* (r) *between each pair of variables.*

Breakages and temperature	·048 ± ·040
,, ,, relative humidity	— ·129 ± ·040
Temperature and relative humidity	— 453 ± ·031

The results show a small positive, but not significant correlation between breakages and temperature, but a negative correlation between breakages and relative humidity. In order to determine the correlation between each pair of variables for a constant value of the third, the partial coefficients have been evaluated and are given in Table XXI.

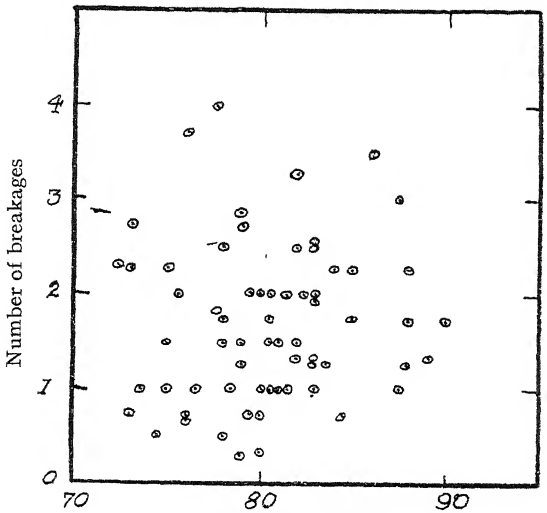
TABLE XXI.—*Giving the partial coefficients of correlation.*

Breakages and temperature (relative humidity constant) ..	— 011 ± ·040
Breakages and relative humidity (temperature constant)	— ·120 ± ·040

In each case the correlation is small and negative, but it is again not significant between breakages and temperature.

The results show that within the limits observed, there is no significant and regular relationship between the number of warp breakages and temperature or humidity, *i.e.*, as the temperature or humidity increases, there is no regular decrease in the number of breakages. The strength of the yarn seems to be affected by other variables besides temperature and humidity, and it is highly probable that the most important of these are inequalities in the warp due to original differences in the quality of the yarn, and variations due to the effect of preceding processes, especially sizing. The same warp under the same conditions of temperature and humidity frequently shows variations in the number of single thread breakages which are greater than those caused by actual differences in temperature and humidity. The results suggest that in general, more attention should be paid to the quality of the yarn and to its treatment in preceding operations, in order to increase the uniformity in the material used in the weaving process.

In order to illustrate the variability in the results, and the absence of a definite connection between the number of breakages and relative humidity, the number of breakages corresponding to different degrees of relative humidity when the temperature was constant (70° F.) are given in graphical form in Fig. 26.



Relative humidity.

Fig. 26.— Relation between breakages and relative humidity.

If an increase in relative humidity caused a proportionate decrease in the number of breakages, the points on the graph would lie approximately along a straight line. Actually they are scattered indiscriminately over the figure and even the most elastic imagination would fail to resolve them into a straight line. It is this absence of regularity or non-linearity which makes it impossible to find the mathematical relation between the two variables and which suggests the existence of other factors that interfere with any possible connection between them. These results were obtained from a weaving shed under ordinary industrial conditions yet they are very similar to laboratory tests on the breaking strength of single threads, and support the views put forward in connection with those results.

In sheds F and G, containing automatic looms, several observations on the number of yarn breakages have been made at different times during the period of the investigations. The values given in Table XXII refer only to breakages in the warp, since weft breakages occurred so seldom as to be almost insignificant.

TABLE XXII.—*Average number of warp breakages per hour (Automatic looms.)*

Shed	No. of obsr. (loom hours).	Warp breakages per loom per hour.	M V.	Mean Temperature.				Rel Hum.	M.V.
				Dry Bulb	M.V	Wet Bulb.	M.V		
F	404	3 8	2·1	69·1	3 3	63·0	3·5	69%	4·6
G	972	2·6	0·6	75 9	1·8	72·6	1·8	83%	2·8

The results show that in both sheds the number of warp breakages per hour on each loom is very small, and indicate the high efficiency and automatic nature of the weaving process on Northrop looms. These conditions enable a weaver in such sheds to have charge of 20 to 24 looms, as compared with only three or four ordinary Lancashire looms.[1] The breakages in shed F are more numerous than in shed G, a fact which may be connected with the difference in temperature and relative humidity observed in the two sheds. In shed G, the temperature and humidity at the time of the observations were much more uniform (M.V.=1·8 and 2·8) than in shed F (M.V.=3·3 and 4·6), and the smaller variability (M.V.=0·6) in the results obtained in shed G is probably attributable to this fact.

For comparative purposes the number of breakages observed in sheds A and D, which contain Lancashire looms, are given in Table XXIII.

TABLE XXIII.—*Average number of yarn breakages per weaver per hour. (Four-loom weavers, Lancashire looms)*

Shed.	Hours observed.	Weft brk	M V.	Warp brk	M V	Counts used.	
						Weft	Warp
A	24	19·4	4·7	14·9	2·6	80's	60's
B	35	19·6	6·7	8·0	3·4	28's	26's

Although the total duration of the observations is much less than in sheds F and G, the results are fairly representative of the number of breakages in the sheds under consideration.

It will be seen that the number of warp breakages in sheds A and D greatly exceed the number observed in sheds F and G, and that they are much more numerous in shed A than in shed D. The chief difference, however, between the two types of sheds lies in the large number of weft breakages recorded in the sheds containing Lancashire looms; a state of affairs which could not be tolerated in the Northrop sheds.

(b) LOOM SPEEDS.

The production of cloth in a weaving shed also depends upon the speed of the looms. A high efficiency does not necessarily imply a large output, since looms running at a slower speed may give a higher efficiency but lower output than those working at a quicker rate.

[1] Although Northrop looms are only suitable for special kinds of work and conditions, the relatively small number in use in the Lancashire Cotton Industry is probably due in part to the conservative nature of the

In sheds F and G, which contain automatic looms, the average weekly efficiency throughout the period of the investigation is 92·2 per cent. in shed F and 86·6 per cent. in shed G. In shed F, the looms included in this investigation ran at an average speed of 172 picks per minute, consequently the average amount of cloth woven by each loom per hour is 9,515 picks. In the case of a shed containing Lancashire looms, running at an average speed of 195 picks per minute, and giving an average efficiency of 86 per cent., the amount of cloth woven by each loom per hour is 10,062 picks, or 5·8 per cent. more than the Northrop looms. Thus a Lancashire loom, with its greater speed but lower efficiency, produces more cloth in a given time than a Northrop loom, but whereas one weaver is only able to look after three or four looms of the former type, she is able to control 20 or 24 in the Northrop sheds.

In weaving, an optimum relation exists between loom speed and efficiency for different classes of cloth. An increase in the speed of the loom beyond a certain point results in an increasing number of warp breakages,[1] consequently a speed is usually chosen which will give the highest output compatible with the quality of the cloth and the ability of the weaver to attend to breakages. Once the most suitable speed has been chosen, it is clearly the interest of the management and the loom overlookers to see that it is maintained, but results obtained during the course of this investigation show that considerable variations are allowed to exist. For instance, in a shed in which 40 looms were under observation the average speed of the looms was 194 picks per minute. The mean variation of the individual speeds from the average was 2·3 and the lowest and highest speeds were 184 and 198 picks per minute respectively. These looms were weaving exactly the same class of cloth and should therefore have been running at the same speed. If 194 picks per minute is the most suitable speed for this class of work, then the output on a loom running at 184 picks per minute will show a decrease in output of approximately 5 per cent. Such a result is undesirable from the standpoint of both the employer and the operative ,and in a well-regulated shed a decrease in output of only 1 per cent. due to slow-running looms should not be tolerated.

Thus the efficiency of production is directly dependent upon physical and mechanical factors such as those mentioned in the preceding pages, and since these are more easily understood and

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[1] In one case, for instance, the management thought it desirable to reduce the speed of the looms controlled by one operative The latter resented the change and prepared to find work elsewhere The management, however, induced her to work the looms at the reduced speed for a month and guaranteed her an increase of 2*s*. in her average wage. At the end of the month, the operative found that her output had increased by approximately 20 per cent because of the decrease in the number of yarn breakages. This decrease meant less work for the operative and increased ability to attend to the breakages which did occur.

controlled than variations in the working capacity of the operatives, every effort should be made to regulate them so as to give the most efficient working conditions.

V. SUGGESTIONS AND APPLICATIONS.

The results of the present investigation show that, within limits, the efficiency in humid sheds continues to increase as the temperature and humidity increase, but beyond a certain point the efficiency may remain the same or even decrease, with increase in temperature and humidity. This point appears to occur when the dry bulb temperature approaches 80° and the wet bulb 75°.

The amount of humidity allowed by law for different temperatures is as follows :—

Dry Bulb.	Wet Bulb	Relative Humidity
70·0	68·0	88 per cent
75·0	71·5	81·5 ,,
80·0	75·5	77·5 ,,

Thus from 70° onwards the percentage of permissible humidity decreases and the beneficial effects of increasing temperature on the warp are neutralised. Hence from the standpoint of the warp, very little increase in efficiency can be expected under existing regulations when the dry bulb temperature exceeds 70°.

From the standpoint of the weaver, hot, moist atmospheres are undoubtedly undesirable, and wet bulb temperatures higher than 75° have been condemned ; it has, indeed, been strongly recommended that they should never exceed 70°.

Taking all factors into consideration, the results of this investigation show that in humid sheds of the type under consideration, the best conditions for weaving will be given by a dry bulb temperature of 70–75°, and a relative humidity of 80–85 per cent. This statement refers to efficiency of production, and does not imply that such conditions are the most suitable for the operation.

Since, however, the number of yarn breakages would be reduced if the temperature and relative humidity of the air were further increased, the possibility of further humidifying the warp, but not the weaver, must be considered. If the weaver were not exposed to the hot, moist air, there would be no objection to enveloping the warp in a very humid atmosphere. To do this it would be necessary to have a fairly normal atmosphere throughout the shed and a hot, humid atmosphere around each warp. In other words, some system of local humidification of looms would have to be adopted. Experiments along these lines have been made, but the results appear to have been unsatisfactory. If, however, very high temperatures and humidities are considered

necessary for the manufacture of certain classes of cloth, the highest efficiency will only be obtained by the adoption of some system of local humidification, and further experiments on the subject appear desirable.

If the industry is content with existing conditions, then the chief problem is to keep the summer temperature within reasonable limits or to reduce its harmful effects upon the weaver. Methods involving the use of atomised water[1] or conditioned air are used in some cases, but these systems appear to be capable of further development. An apparatus which is said to maintain a dry bulb temperature of 72·5°, and a relative humidity of 80 per cent. throughout the summer months, is now on the market.

Everyone is familiar with the invigorating effects of a breeze on a hot day, and some attempt should be made to apply the principles involved to the weaving shed. The particular method employed may take the form of a general circulation of the air in the shed by means of fans, or the increased air movement may be confined to the vicinity of the weaver, or a combination of the two methods may be adopted In any case, increased air movement is very desirable, and the method of creating it of secondary importance[2].

The above suggestions have been advanced in order to reconcile to some extent the atmospheric conditions demanded by the warp and the weaver, respectively. It seems to be established beyond doubt that the conditions which are best for the yarn are unsuitable for the operatives, and the adoption of one or more of the suggestions will materially improve the conditions during the hot summer months. At the same time, the possibility of discovering some new method of treatment of the yarn, which will enable it to be woven without the assistance of a high degree of humidity, must also be kept in mind.

A high temperature and humidity are only necessary when the yarn used in the weaving process is impregnated with size, and the unsatisfactory atmospheric conditions prevalent in humid sheds during the summer months would be unnecessary if a substitute for size could be discovered. The importance of research on this question cannot be too strongly emphasised, for the abolition of "steaming" would immediately result in improved conditions of work, giving greater bodily comfort to the operatives, better health, and increased efficiency.

The results of this investigation show that a high efficiency is obtained in weaving sheds of the type under consideration. These sheds are recognised as among the most efficient in the cotton industry; consequently the variations observed would probably

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[1] For experimental results obtained by using these methods, see "Second Report on Humidity and Ventilation in Cotton Weaving Sheds," 1911, pp. 37–39 (Cd 5566)

[2] "Atmospheric Conditions in Humid Weaving Sheds," Report No 21 of the Industrial Fatigue Research Board

be considerably magnified in sheds of a less efficient type. In sheds engaged in weaving fancy fabrics, the efficiency is also relatively low, because of the more complicated nature of the work and the finer quality of the yarn used in the weaving process. A similar investigation in such sheds should be carried out because of the greater dependence of the operations upon human capacity. Since the aim of the present investigation was to obtain results which would indicate the effect of existing conditions in the manufacture of plain cloth in humid weaving sheds, it was realised at the outset that one of the chief values of the inquiry would be its suggestive nature. In this respect, the possibility of comparing results from "dry" and humid sheds, in which the conditions of work are otherwise similar, should be considered. For this purpose it would be necessary to select humid and dry sheds in which the conditions of work are otherwise similar, and to determine the hourly variations in efficiency over a period of not less than three months, preferably in summer. The number and nature of yarn breakages in the two types of shed should also be determined, in order to obtain an estimate of the amount of effort expended by the weavers in the respective sheds.

The value of the investigation would be further increased if the cheek and body temperatures of the weavers in the dry and humid sheds were determined in the manner described by Legge and Collis in connection with weavers in human sheds.[1] Since the absence of artificial humidity in dry sheds tends to give rise to a dusty atmosphere, a determination of the nature and amount of atmospheric dust in dry sheds would also be valuable.

The ultimate effect of artificial humidity upon the operatives can only be ascertained by a study of sickness and mortality records. It would be necessary to choose a town containing both "dry" and humid sheds weaving approximately the same kind of cloth, and to keep records of the extent of sickness and mortality among the operatives employed. Unfortunately, such records are not to be found at the mills, but their compilation would constitute a valuable piece of work for welfare supervisors to undertake. Some data are in the possession of the Trade Unions, but the records refer chiefly to the war period, and are consequently of little value now. A careful statistical treatment of accurately compiled sickness returns would provide the logical and final argument to the dispute regarding the effect of humidity upon the operatives, and would clinch all the conclusions arising out of efficiency investigations. It is sincerely hoped that an inquiry of this kind will be undertaken at the earliest opportunity.

The method employed and the results obtained in the present investigation illustrate the importance and value of efficiency records. With few exceptions, practically no attempt is made in the cotton industry to determine the exact efficiency of production on each loom, with the result that many instances of decreased

[1] Second Report of the Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds, 1911.

efficiency and their causes pass unnoticed. This lack of information is largely due to the effect of traditional methods upon the attitude of employers, who usually hold the belief that what was good enough for their fathers and grandfathers is good enough for them.

Many employers hold the natural view that a man is not profitably employed unless he is actually producing, and consequently the clerical staff of the establishment is reduced to an absolute minimum. The possibility of creating a statistical department has certainly seldom been entertained. Efficiency records would not only yield a mass of valuable information, but would also stimulate managers and employers to take a scientific interest in their work. These records could be used to determine the percentage of unproductive labour in the case of different operatives in different processes. This would give the extent of individual variations in efficiency and would lead to an investigation of the possible causes of such variations. They may, for instance, be either mechanical in origin, as in the case of loom speeds, variations in the quality of the yarn used, and other conditions of work, or human, due to variations in the ability of the operatives, which may be either permanent or temporary. The lost time or efficiency could then be classified as avoidable or unavoidable, and attempts made to remove causes of inefficiency coming within the former category. In this way the management would be able to acquire a more intimate acquaintance with the causes and conditions of inefficiency and take steps for their removal. The determination of the exact relation between cause and effect would not only result in a general increase in efficiency, but would also enable the management to take a more intelligent and sympathetic interest in the work of the operatives The assimilation of the fact that efficiency records are worth collecting will be a slow process, but will be accelerated by the progress made in this direction by the more progressive firms.

One of the chief causes of individual differences in weaving efficiency is undoubtedly innate differences in the capacities required in the weaving process Operatives deficient in one or more of these capacities are usually less efficient and find the work more difficult and fatiguing than their more fortunate neighbours As a result they sometimes become dissatisfied and worry over their disabilities. Probably, therefore, the less efficient operative might be more suitably, efficiently, and congenially employed in another department of the mill, or even in some other industry, instead of remaining at an unsatisfactory operation or leaving it after several years for more suitable conditions of employment. The advantages of guiding an individual at the beginning of her industrial career into the occupation for which she is most suited are at once obvious, and there accordingly seems to be a need for the application of vocational tests in the weaving section of the cotton industry. For the successful application of such tests, the supply of prospective weavers needs to be in excess of the demand,

and the desires of the individual must be taken into account as well as her abilities. Some scientific system of guidance would, however, reduce the number and extent of the misfits which at present exist, and lead to a greater economy of human effort together with an increase in productive efficiency.

The most suitable individuals for the weaving process having been selected, the logical sequence is to train them in the best method of work, and a scientific study of the principles involved is desirable. This may take the form of a careful analysis of the methods employed by the most efficient workers and the training of recruits in these methods by experienced weavers who are also capable teachers.[1] By these means it would be possible to avoid the formation of unsuitable, uneconomical, and fatiguing habits of work, leading to a speedier realisation of a high degree of efficiency with its accompanying elements of personal satisfaction. If it is considered necessary to train a person in the correct methods associated with various athletic performances, it is even more essential to instruct industrial workers in the methods of doing work.

As regards the more objective factors connected with the weaving process, it is suggested that some experiments might be made on the most suitable speed for looms. At present, there are sometimes considerable differences in the speed of looms weaving the same kind of cloth, and more accurate information on the optimum speed for each class of cloth would be very valuable. To obtain such information it would be necessary to keep a careful record of the nature, number, and duration of loom stoppages for different loom speeds when all other factors are kept constant. From these results it might be possible to determine the most suitable speed bearing in mind the effect of yarn breakages upon the quantity and quality of cloth woven and the number of looms per weaver.

An associated question is the determination of the most suitable number of looms per weaver. The solution of the problem will depend upon such factors as the innate ability of the weaver, the kind of cloth woven, and the standard of work required by the management. At the present time weavers working on Lancashire looms are in charge of a varying number, from two to six; but in Northrop sheds one weaver may control 24 looms. Under uniform conditions of work it seems probable that individual differences in weaving ability should be accompanied by differences in the number of looms supervised. For instance, a three-loom weaver producing an average efficiency of 55 per cent. may be much happier and obtain better results if she had only two looms. Similarly a weaver who is able to get an average efficiency of 90 per cent. from three looms might be given

[1] This method of procedure has been adopted by Elton in silk weaving. (*See* An Analysis of the Individual Differences in Output in Silk Weaving. *Ind. Fat. Res. Bd. Report, No.* 17.)

a fourth. It frequently happens that an efficient weaver refuses to have the responsibility of working an additional loom, and others break down completely under such circumstances. There are many psychological and economical aspects to such a question, but a careful experimental investigation along such lines would undoubtedly give interesting and instructive results.

For the results presented in this report, the writer is extremely indebted to the management of the different sheds for the facilities and help so generously provided. Similar obligations are due to the Trade Union representatives and operatives for their invaluable co-operation and assistance. Without their active support this investigation would have been impossible. Because of the nature of the results obtained, constant appeals for advice and guidance to the Statistical Department of the Medical Research Council were necessary, and in this connection, the help of Miss E. M. Newbold and Miss E. C. Allen is particularly appreciated. Finally, the patience and perseverance of the assistants employed in the collection of over a million readings cannot be praised too highly. In many cases, the duties were most exacting and monotonous, yet they performed them without complaint. To all who assisted in the compilation of this report, the writer would like to offer his most sincere thanks.

VI.—SUMMARY.

1. The productive efficiency in four of the humid sheds containing ordinary looms is very high (approximately 85 per cent.), and illustrates the degree of efficiency attainable in sheds in which plain cloth is woven under good conditions. In the more difficult operation of weaving dhooties, the average efficiency may fall to 77 per cent. (shed A) (p. 7). The average efficiency in the sheds containing automatic looms is also high (92·2 and 86·6 per cent.), but owing to the slower speed of the looms in these sheds, the output per loom is slightly less than in the sheds containing ordinary looms (p. 47).

2. The efficiency for any given shed is very uniform throughout the year, week, or day. This uniformity is due partly to the predominating influence of the mechanical factor and partly to the fairly constant atmospheric conditions intentionally maintained inside the shed (p. 7). This general statement, however, is subject to certain qualifications, and the following definite tendencies have been observed :—

(*a*) In some sheds the efficiency on Saturday morning is very low. This is largely due to the sweeping and cleaning of looms which takes place on this morning (p. 10).

(*b*) Under normal conditions, undisturbed by the effect of temporary incentives to work, the efficiency on Monday morning is relatively low. This is due to the effect of the week-end break upon the operatives, and on the material. Tuesday is, generally, the most efficient day in the week (p. 10).

(*c*) Efficiency usually increases immediately before the "booking-up" period, and is often affected by the particular system adopted in booking-up (p. 32).

(*d*) In a shed working on the two-break day system, the efficiency during the pre-breakfast spell is consistently low, being about 2 per cent. less than that of the second and third spell (p. 9).

3. The rate of output has been found to diminish during a period of "short time" introduced owing to trade depression; this appears to be due to the modified attitude of the operatives towards their work (p. 33).

4. The general belief that in humid sheds of the type under consideration, output, within certain limits, increases as the temperature or relative humidity increases, is supported by the results of this investigation, which suggests that output varies directly as the product of the two (p. 17). In a dry shed, on the other hand, the variations in temperature and humidity observed seem to have very little effect on output (p. 18).

5. There are signs of a progressive change in the shape and direction of the morning curves during the course of the week. The point of maximum efficiency tends to move from the end of the morning spell on Monday to the beginning of the spell on Friday, and occupies intermediate positions on the other mornings of the week. This tendency is most easily explained in terms of fatigue (p. 38).

6. The initial rise and final fall in efficiency discernible in the daily work curves are not due (as is sometimes alleged) to extraneous causes, such as lateness in starting, etc , but are of subjective origin and represent a real quickening up and slowing down (p. 39).

7. When the average temperature for the afternoon spell is comparatively low, the efficiency in humid sheds tends to remain at a fairly uniform level throughout the spell. When the average temperature is high, the efficiency decreases as the afternoon advances. The greater decrease in efficiency when the higher temperatures prevail is due to the effects of the atmospheric conditions upon the weaver (p. 41). Thus atmospheric conditions which are best for the warp are unsuitable for the weaver, and if maximum efficiency is to be maintained, the warp must be placed in a different atmosphere from that which surrounds the weaver (p. 48).

Under existing regulations, the best conditions for productive efficiency in weaving in humid sheds of the type under investigation seem to be obtained with a dry-bulb temperature of 70–75° F., and a relative humidity of 80–85 per cent. (p. 48).

8. In the weaving process, variations in the working capacity of the operatives are inadequately expressed in efficiency percentages because of the overwhelming effect of the mechanical factor. A modified method of treating the results, which reduces the effect of this factor, shows that the time required to attend to loom stoppages is greater in the afternoon than in the morning spells of work, and increases progressively throughout both the day and the week. These variations in working capacity, although they have no appreciable effect upon output, are important as indicating the extent to which fatigue may be present in weaving (pp. 34–38).

9 The quantity and quality of artificial light used during the winter months affects production, but the extent of the effect is different in the different sheds. The increase in output as the proportion of work done under artificial light decreases is most marked in shed D, and in the hours most affected the difference in efficiency is from 4 to 6 per cent. (p 21).

Differences in shed construction, especially in connection with roof lights, may have an important influence upon the nature and duration of natural and artificial illumination during the darker months of the year (p. 19)

The system of lighting at present adopted in weaving sheds gives rise to a considerable amount of glare and disturbing shadows. These conditions are unsatisfactory and conducive to discomfort and fatigue (pp. 26, 27).

10. In the two-break day the proportion of work done under artificial light is greater than in the one-break day. In a shed in which the former system was adopted the efficiency of the pre-breakfast spell in winter was 8·7 per cent. less than that of the second spell, but in summer the difference was only 1·7 per cent. Similarly the efficiency of the third spell in winter was 6·1 per cent. less than that of the second, but in summer it was 1 per cent. more (pp. 23–25).

11. Considerable differences exist in the individual efficiencies of weavers, indicating the desirability of some form of vocational selection (p. 28)

12 Weaving efficiency is sometimes seriously affected by variations in the quality of the yarn and inequalities due to sizing. Variations due to these causes are often much greater than those due to variations in temperature or humidity (p. 43).

APPENDIX I.

Method of Correcting Pick Recorder Readings

The readings from the pick recorders were taken at the following times :

Morning spell .. 8 15, 9 15, 10 15, 11 15, and 12 15
Afternoon spell .. 1 30, 2.30, 3 30, 4.30, and 5 30

As the result of several preliminary trials, it was found that the times required to take the readings in the different sheds were :—

Shed	A	..	8 minutes.
,,	B	.	5 ,,
,,	C	..	12 ,,
,,	D	..	10 ,,
,,	E	..	4 ,,

Consequently it was necessary to arrange a system which would enable the same number of readings to be taken before and after each of the times given above. Thus in the case of shed A, the assistant would begin to take the readings at 8 11 and would complete the round at 8 19, thereby ensuring an equal distribution of the readings around 8 15, and the average of these represented the value which would have been obtained if all the readings had been taken simultaneously at 8 15. A similar method was adopted in the case of the other times given above, with the exception of the times 12 15 and 5 30, which represent the end of the morning and afternoon spells In these cases all the readings were taken after the looms had stopped, so as to obtain the total output of each loom for each working spell

In an extended investigation of this type, small deviations from the theoretical times when the readings should be taken must necessarily occur. In such cases the required correction was always applied, as the following examples illustrate —

Table A —*Method of Correcting Output Readings*

Theoretical Time	Actual Time Taken.	Average of Time Taken	Productive Interval.	Actual Output.	Corrected Output.
8 15	8 10–8 18	8 14	29 mins.	46·0°°	47 6°°
9.15	9 11–9 19	9 15	61 ,,	93·2	91·7
10 15	10 10–10 18	10 14	59 ,,	94·0	95·6
11 15	11.12–11 18	11.15	61 ,,	92·8	91·3
12 15	12 15	12 15	60 ,,	90·6	90·6

(The output is given in hundreds of Picks)

Whenever the engine failed to stop at exactly the scheduled time at the end of the working spell, the actual stopping time was noted and the necessary correction applied to the results.

The pick recorder readings were always taken in the same order, and to ascertain the actual number of picks woven each hour it was necessary to subtract each of the readings from the one taken an hour later This operation was performed by the assistant during the interval between each round, and the results entered upon a special form. In this way any unusually low readings could be detected without loss of time, and the causes usually traced Coupled with this procedure an arbitrary standard of rejection was adopted for unusual results due to exceptionally long stoppages of a mechanical origin The most frequent stoppages of this kind were due to mechanical defects or breakages in the loom, and to the changing of warps The latter process only occurred once every four to six weeks, and only the hourly averages at the time of, and immediately following, the stoppages were affected.

APPENDIX II.

Correlation Coefficients

The relation between temperature, relative humidity, and output has been determined quantitatively by means of the method of multiple-correlation. Were the output to vary directly with temperature or relative humidity (i e , an increase in output to be accompanied by a proportionate increase in temperature or relative humidity), then the coefficient of correlation (r) would be unity Should an inverse relation exist (i e , an increase in output be accompanied by a proportionate decrease in temperature or relative humidity), the coefficient of correlation would be -1 If there is no relation between output and either of the other two variables, r will be equal to zero, unless the frequency surface is of a very uncommon type. Thus all degrees of relationship will be represented on a scale between $+1$ and -1

For the purposes of correlation, readings obtained during 15 to 22 weeks in the summer period (April to September) in sheds A, B, C, and H were used Holiday weeks, and the weeks before and after the summer holidays, were excluded because of the abnormal incentives to work existing at those times. The actual results used in the calculation were the morning and afternoon averages (excluding Saturday), but the incomplete hours at the beginning of each spell were excluded because they were affected by the time lost in starting work

Each correlation series consisted of the averages obtained in the same spell in the different weeks, thus, ten sets of correlation coefficients corresponding to the morning and afternoon spells from Monday to Friday, were obtained for each shed.

The total and partial correlation coefficients[1] are given in Table B.

On the whole no consistent correlation between output and temperature or relative humidity that applies to all the sheds can be traced

To take the sheds separately, sheds A and C give values that are too variable to establish any definite relation between output and temperature or relative humidity.

Shed B, however, shows a *significant* [2] and fairly high positive correlation

[1] The total correlation coefficient measures the extent of the relation between two variables The partial correlation coefficient measures the extent of the relation between two variables independently of their respective relations to a third variable Thus in the results obtained in this investigation, output is dependent upon both temperature and relative humidity, and the partial correlation coefficient measures the closeness of the interrelation between output and either temperature or relative humidity when one of the latter variables is kept constant.

[2] The probable errors of the r's are not given, as the samples are too small for the usual formula to hold, but the distributions were tested by the tables in Biometrika XI, as follows :—

	Mean Partial Correlation Coefficients				No in Samples.
	Output and Temperature (Humidity constant.)	Theoretical Standard Deviation	Output and Relative Humidity (Temperature constant)	Theoretical Standard Deviation.	
Shed B ..	·557	·1645	·222	·2192	20
Shed H ..	—·134	·2143	—·089	·2641	22

In all four cases the deviations of each of the ten observed r's (with one exception in B marked *) from their mean is less than $2\frac{1}{2}$ times the theoretic standard deviation for samples of the same size.

TABLE B

Correlation between Output, Dry Bulb Temperature, and Relative Humidity

Summer Period, April–September, 1920.

Shed	Day	Total Correlation. Coefficients			Partial Correlation Coefficients.		No of Observations.
		Output and Dry Bulb	Output and Relative Humidity.	Dry Bulb and Relative Humidity.	Output and Dry Bulb (Relative Humidity constant)	Output and Relative Humidity (Dry Bulb constant)	
A	Mon. a m.	·064	·358	—·617	·388	·506	17
	Tue. a m	—·012	·085	— 551	·042	·094	17
	Wed. a m.	·177	—·330	—·496	·016	—·283	17
	Thu. a.m	078	326	—·151	·136	·399	16
	Fri. a.m	129	—·132	—·762	·045	—·052	15
	Mon. p.m.	161	—·169	—·298	·224	—·230	17
	Tue p m	—·377	·237	—·625	—·303	·002	17
	Wed. p m.	056	·005	— 570	·072	·046	16
	Thu p m	—·186	·661	—·779	·700	·838	15
	Fri p m.	—·143	·343	—·646	·109	·331	15
B	Mon a m.	— 112	·144	— 524	·222	·240	20
	Tue a m	691	·168	— 228	·760	·462	20
	Wed a m	·707	—·042	—·210	·715	·154	20
	Thu. a.m	·691	·029	—·126	·700	·163	20
	Fri. a m	·486	·051	— 355	·540	·274	19
	Mon. p.m	·297	·318	— 584	·627	·633	20
	Tue p.m	·408	—·471	—·471	·239	—·347*	20
	Wed p m	·596	—·208	— 495	·580	·118	20
	Thu p.m	·504	·054	—·454	·594	·367	19
	Fri p m	·613	—·243	—·558	·593	·152	20
C	Mon a m	·023	—·032	—·721	—·0003	—·022	20
	Tue a m	·339	—·258	—·752	·227	—·005	20
	Wed. a m.	·406	·001	—·608	·512	·341	19
	Thu a m	·012	·002	—·206	·013	·004	20
	Fri a m.	·268	·128	—·190	·300	·189	20
	Mon. p m	—·351	·180	—·832	—·368	—·215	20
	Tue p.m	—·011	—·166	—·285	—·062	—·176	20
	Wed p m	—·043	436	—·663	·365	·545	20
	Thu. p.m.	·120	·441	—·410	·368	·542	19
	Fri p m	·002	·146	—·623	·120	·188	20
H	Mon a m	·466	—·398	—·382	·371	—·270	22
	Tue a m	—·219	—·283	—·316	—·339	—·381	22
	Wed a m	·158	·154	—·079	·172	·169	22
	Thu a m	·070	—·061	—·134	·062	—·053	21
	Fri a m	—·136	·204	—·253	—·089	·177	22
	Mon p m	·021	—·135	—·314	—·023	—·136	22
	Tue. p.m	—·239	—·098	·017	—·239	—·097	22
	Wed p m	—·201	—·173	—·240	—·254	—·232	22
	Thu p m	—·453	151	—·347	— 432	— 007	21
	Fri p m.	—·619	·307	—·554	—·567	—·055	22

between output and temperature (relative humidity constant) and a small positive correlation, not necessarily significant, but probably so in view of the consistence of the samples, between output and relative humidity (temperature constant).

Shed H shows small negative correlations, in both cases these again are not necessarily significant having regard to the size of their error, but in view of their consistent negative values in most of the samples they are probably significantly negative though small

The difference between the correlation results of shed B and those of the other sheds is probably due to the fact that in shed B variations in temperature and relative humidity during the summer period are comparatively large, but in the other sheds a high degree of uniformity exists Owing to original or acquired variations in the yarn itself, it is very improbable that an increase of one or two degrees in temperature or relative humidity will always be accompanied by an increase in output, only when the variations in temperature and relative humidity are considerable can the effects hope to be adequately reflected in the output results.

Thus the indefinite correlation coefficients obtained in connection with sheds A and C may well be due to uniformity in the atmospheric conditions in the sheds, while the significant results obtained from shed B owe their existence to the relatively large variations in temperature and relative humidity.

The small number of observations (20) available for correlation purposes in each series also gives rise to much variability

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MEDICAL RESEARCH COUNCIL.

INDUSTRIAL

FATIGUE RESEARCH BOARD.

REPORT No. 24.

A Comparison of Different Shift Systems in the Glass Trade

By E. FARMER, M.A.

(Report on an Investigation promoted by the Industrial Fatigue Research Board and the Glass Research Association.)

LONDON:

Printed and Published by His Majesty's Stationery Office, and to be purchased at any of the addresses shown on opposite page

1924.

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To suggest problems for investigation, and to advise upon or carry out schemes of research referred to them from time to time by the Medical Research Council, undertaken to promote better knowledge of the relations of hours of labour and of other conditions of employment, including methods of work, to functions of the human body, having regard both to the preservation of health among the workers and to industrial efficiency; and to take steps to secure the co-operation of industries in the fullest practical application of the results of this research work to the needs of industry.

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PREFACE.

In 1921 the Board were approached by the Glass Research Association with an invitation that they should take part in a joint investigation dealing with the physiological and psychological aspects of work in glass factories, on the understanding that in addition to actual collaboration, a substantial part of the expense should be defrayed from the funds of the Association. The proposal was cordially welcomed by the Board, and since the beginning of 1922 the investigation, which was entrusted to Mr. Farmer, assisted by Mr. R. S. Brooke and Mr. E. G. Chambers, has been in progress under the direct supervision of the following Committee composed partly of members of the Glass Research Association and partly of nominees of the Board :—

R. S. Biram ; G. E. Alexander, O.B.E. ; C. C. Paterson, O.B.E. ; S. N. Jenkinson, M.B.E. ; F. G. Clark ; J. Forster, O.B.E. ; E. Meigh, M.B.E. ; T. C. Moorshead ; J. Northwood ; E. J. Purser (*Representatives of the Glass Research Association*).

E. L. Collis, M.D., M.R.C.P., D. R. Wilson, M.A., (*Nominees of the Industrial Fatigue Research Board*).

A preliminary survey showed clearly that the elucidation of general principles in the glass industry must be attended with special difficulties, owing largely to the variations in the articles made and the methods of manufacture. It seemed therefore more profitable to concentrate attention in the first instance chiefly on a definite problem of practical importance to the trade, on which opinion is to some extent divided, viz., the relative merits of the 10-hour and the 8-hour shift systems.

The present Report tends to show that there is almost consistently an increase in the hourly rate of output (as well as a decrease in the amount of spoilt work) in the 8-hour shift as compared with the 10-hour shift. The effect on output of shifts of different length has already been investigated for the Board by Dr. H. M. Vernon in the tinplate [1] and steel [2] industries, where the conditions of work have many features in common with those in glass manufacture. In these investigations comparison was made between shifts of length other than 10 and 8 hours, but the same effect was apparent in nearly every instance, namely an increase in hourly output on the shorter shift as compared with the longer. Very similar conclusions have been reached by the Committee of the Federated American Engineering Societies which recently reported on the 12-hour shift in continuous industries [3].

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In themselves, these increases are usually insufficient to compensate for the shorter hours worked, so that the total output per shift is generally less on the shorter than on the longer. In continuous processes of the kind concerned, however, where production is maintained throughout the 24-hour cycle, hourly output rather than shift output is the more important factor. In such processes, the advantage clearly lies with the shorter shift, and in the particular instance dealt with in the present Report, where previously to the adoption of the shorter shift the work was not carried on continuously but only during 20 hours out of the 24, this advantage becomes still more pronounced.

It is realised, of course, that many other factors (such as local custom, labour supply, piece rate adjustment, transport facilities, etc.) may have to be taken into account in deciding on the best length of shift, and the special relevance of these reports consists in suggesting that in work involving considerable muscular effort and exposure to high temperatures, the physiological state compatible with high output will be maintained at an average level which varies with the length of shift and which within the limits observed is higher the shorter the shift.

The present investigation also shows that output is subject to a marked seasonal variation in output and is greater in winter than in summer, owing doubtless to the comparatively adverse physiological conditions brought about by the higher temperature. Here again exactly similar conclusions were reached by Dr. Vernon in the investigations already referred to [1, 2]. The Board suggest that in view of the considerable diminution in output, pointing to disadvantageous conditions of work, this question is deserving of further and more intensive study, with the object of finding some remedy by increasing the rate of air movement in the neighbourhood of the workers or by other means.

The special thanks of the Board are due to Mr. R. L. Frink, Director of the Glass Research Association, and to Professor W. E. S. Turner, of Sheffield University, for much valuable guidance on technical points.

REFERENCES.

[1] *The Influence of Hours of Work and of Ventilation on Output in Tinplate Manufacture.* (Ind. Fat. Res. Bd., Report No. 1.)

[2] *Fatigue and Efficiency in the Iron and Steel Industry.* (Ind Fat. Res. Bd., Report No. 5)

[3] *The Twelve Hour Shift in Industry, by the Committee on Work Periods in Continuous Industry of the Federated American Engineering Societies.* (Dutton and Co., New York.)

A COMPARISON OF DIFFERENT SHIFT SYSTEMS IN THE GLASS TRADE.

By E. Farmer, M.A. (*Investigator to the Board*).

(Assisted by R. S. Brooke, M.A., M.C., and E. G. Chambers, B.A.)

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Introduction.

The glass industry is one in which the study of the human element in production is attended with special difficulties. So many different articles are manufactured, the methods of manufacture and the length of hours worked vary so much, that it is hard to obtain reliable data which would yield comparisons useful to the industry as a whole. After a preliminary survey and visits to a considerable number of firms, manufacturing various forms of glassware and situated in different parts of the country, it was thought advisable to pay special attention to the problem of the optimum length of the working spell for three reasons.

In the first place, in the Yorkshire district a rearrangement of the working day had taken place in July, 1919. Previously, the day had been divided into two ten-hour shifts, whereas after this date it was divided into three eight-hour shifts. Further, the workers were in all cases paid by results. The conditions, therefore, seemed to be favourable for investigating the effects of this change through the study of the data obtainable from certain firms. These data, although they could not form a basis of comparison between various firms (and therefore between various methods), would nevertheless

afford some indication of the effects of different practices employed at different times by the same firm. It was felt that such an inquiry might produce results of wider interest by showing the presence of some general principle affecting the problem of the optimum length of the working spell, applicable to other districts. Secondly, differences of opinion existed in the trade concerning the advisability of the long and short shift methods, and, therefore, any light which could be thrown on their relative efficiency by an outside observer might be of use to those who were endeavouring to arrange for the most economic working conditions. Thirdly, if any conclusions could be arrived at under the comparatively uniform conditions existing in Yorkshire, concerning the factor of human fatigue—the only factor common to all glass works—deductions might be drawn throwing light on other ways of arranging the working day.

General Description of Processes.

The glass industry in Yorkshire is mainly concerned with the manufacture of bottles, and so one of the many variables affecting this inquiry was removed. The processes of manufacture fall into three categories :—

(*a*) Hand-made.
(*b*) Semi-automatic.
(*c*) Automatic.

(*a*). *Hand-made Processes.*

In the hand-made method, two slightly different processes are in use, both of which have existed almost unchanged for generations.

(i) In the first of these the workers, three in number, are called *flint hands*. Two of these are *blowers*, and the third is the *maker*. Each *blower* gathers the molten metal on his *iron*, rolls it, blows it out in the mould, and then *cuts down* or *bursts off* the bottle into a tray near the *maker*. The *maker* takes the bottle into a *gadget* shaped to fit it exactly, heats the neck for a time in a small furnace or *glory-hole*, and then shapes the neck with a tool specially made for the purpose. The bottle is then finished, and is carried away to the annealing *lehr* or furnace by a boy called a *taker-in*. In this process each gang or *chair* comprises four workers.

(ii) In the alternative process, each *chair* consists of five workers called *bottle-makers*. First, there is a *gatherer* whose duty is simply to gather the molten metal on to an iron. The *blower* takes the iron from him, rolls the metal and blows it out into the mould. Next the *melter-off* takes over the iron from the *blower*, gives a final blow into the mould, and then *wets off* the bottle into the *maker's* tray. The process of *making* the bottle is different here, for the *maker*, after heating the neck, adds a ring of molten metal to the neck before he shapes it with his tool. Finally, the *taker-in* removes the finished bottle to the lehr.

(*b*) *Semi-automatic Processes.*

In the so-called semi-automatic processes there is a large variety of machines in use. The bulk of these have several features in common, and differ chiefly in size and accessory mechanism. The process of making a bottle with one of these machines is as follows :—

The *gatherer* gathers the molten metal from the tank and drops a sufficient quantity into the parrison mould which is then brought in front of the *blower* by rotating the machine. He inverts the mould, opens it, and pats the metal with a movable platform until it has the right consistency. Then he closes the mould and turns on an air-jet which blows the bottle. Finally, the machine is rotated again to a third worker, who opens the mould and removes the bottle, putting it on a tray or roller, whence the *taker-in* removes it to the lehr. This third man also closes the mould and lubricates it, and by the next rotation of the machine it assumes its upright position in front of the *gatherer*.

There is also a type of machine which more nearly approaches the fully automatic machine, the chief difference being that it has to be fed by hand ; the remainder of the process is automatic.

(*c*) *Automatic Processes.*

In the fully automatic processes the whole making of the bottle is done by machinery. The metal is gathered or fed by the machine and blown out by an air-jet, and the only human co-operation necessary is the supervision of the machine.

Methods of Investigation.

Although a large number of firms kindly placed their records at the disposal of the Investigators, comparatively few of these could be used, either because they were kept in such a way that the specific information required for this investigation could not be elicited, or because, owing to changes brought about by the War, some firms had not manufactured one type of bottle for a sufficiently long period to yield reliable data.

Hand-made Processes.—The method adopted was to select bottles which had been made for a lengthy period by the same chairs* under both methods of subdividing the working day. The average output per shift and the average output per hour for these chairs were calculated during each month in the two periods. In order to make the data strictly comparable, periods were chosen as far as possible comprising the same months, so as to eliminate possible effects of seasonal variation.

In certain cases war and post-war periods have been compared but it should be borne in mind that it was always the output of the same chair which was compared, and so the possibility of a less efficient type of labour during the war period affecting the

*A *chair* is a group of men working together on the same bottle.

figures is removed. We were constantly informed by managers that during the war the workers were keener on producing their maximum output than after the war. If this is so, it would tell against the increased hourly output which accompanied the change of shift in 1919, as shown in the following tables, and had this special war incentive not been operating the increase might have been even greater than it is. In certain cases difficulty was experienced during the war in getting a regular supply of coal and raw material, and in order to guard against this interfering factor, no records were used unless they were regarded by those who had kept them as being thoroughly reliable. Many records which were offered to the investigators were not used for this reason alone, and those which are presented in this Report are believed to be trustworthy and as free as possible from external interfering causes.

Table I (*see* page 20) gives the comparison of the average hourly output for various types of hand-made bottles taken from the records of four firms. It shows that in practically every case the hourly output is higher for the eight-hour shift than for the ten-hour shift.* It should also be noted that there appears to be a tendency in three of the factories for the increase in hourly output to be greater with the heavier bottles than with the lighter. This is interesting, not only in view of the already known fact that the period over which the human body can profitably continue to do work involving heavy muscular effort varies inversely with the arduousness of the work, but also because it illustrates the difference between the fatigue due to heavy muscular effort and fatigue due to the constant repetition of a group of intricately co-ordinated movements, involving conscious supervision but comparatively little muscular effort. These records seem to indicate that heavy muscular work involves a type of fatigue which can be alleviated by shortening the working spell, whereas the fatigue involved in the constant repetition of an intricate operation is not relieved by this method to the same extent.

Comparisons, wherever possible were also made between the amount of spoilt work recorded during both periods, and the results are given in Table II. It will be seen that there is a slight decrease in the amount of spoilt work for the lighter bottles, on which the smallest increase of output was made, and an increase in the amount of spoilt work for the heavier bottles, on which the greatest increase of output was made. From this it would appear that the increase in output is not

* Vernon has shown (*The Speed of Adaptation to Altered Conditions of Work*—Ind. Fat. Res. Board Report No. 6) that any increase in output following on reduction of hours is gradual and that a considerable time, amounting sometimes to 13 months, often elapses before equilibrium is established. In the present investigation it was not always possible to secure data over a sufficiently long period to ensure that the rise in output had reached its maximum, hence the figures given here and elsewhere may not perhaps represent the full benefit of the shorter shift.

entirely due to lessened fatigue, but is also partly accounted for by the natural desire of the workers to increase their output during the shorter hours so as to bring up their earnings to their previous standard It should, however, be borne in mind that the standard of inspection was raised considerably in the years 1920 and 1921, when the effects of the war demand were drawing to a close and the ordinary process of competition taking its place. Moreover, it is easier to spoil a large bottle than a small one, and this may account in some degree for the increased amount of spoilt work in the case of the heavier bottles as compared with the decreased amount of spoilt work in the case of the smaller bottles

A third way of comparing the relative efficiency of the two methods of dividing the working day was to investigate the amount of time lost under both systems. Unfortunately, records dealing with this subject could only be obtained from one firm, and so too much reliance should not be placed upon them; they are, however, given for what they are worth in Table III.

The time lost has been divided into two classes :—

(1) All absences except those extending over four or more consecutive weeks. (Special circumstances made it advisable not to include those absences of more than four weeks, because during the earlier period, two workers underwent operations for complaints entirely unconnected with their occupation, and if these absences had been included, the difference between the two periods would have been made to appear greater than they were likely to be when these special circumstances were absent.)

(2) Absences of two days and under. (No absence less than a whole shift was counted, but a distinction between the long and short absences was made, since the short absences are probably the more important indications of fatigue.)

It will be seen from Table III that there is a slight decrease in the amount of time lost during the shorter shift period compared with the amount of time lost during the longer shift period. The difference is a small one, and before this conclusion can be regarded as definite, further evidence must be collected.

Semi-automatic Processes.—Similar data obtained for the semi-automatic method of glass blowing are given in Tables IV and IVa. The former shows that there is an increase in hourly output in every case coinciding with the introduction of the shorter shift.

The output for Factory 3 shows an increase of only 5·3 per cent. compared with that of 35·5 per cent. for Factory 5, making the same article but with a different type of machine. This difference is probably due to the fact that in Factory 3 (previously to the change in shift), a far higher standard of output had already been attained than in Factory 5, so that any increase in hourly output would be proportionately more difficult.

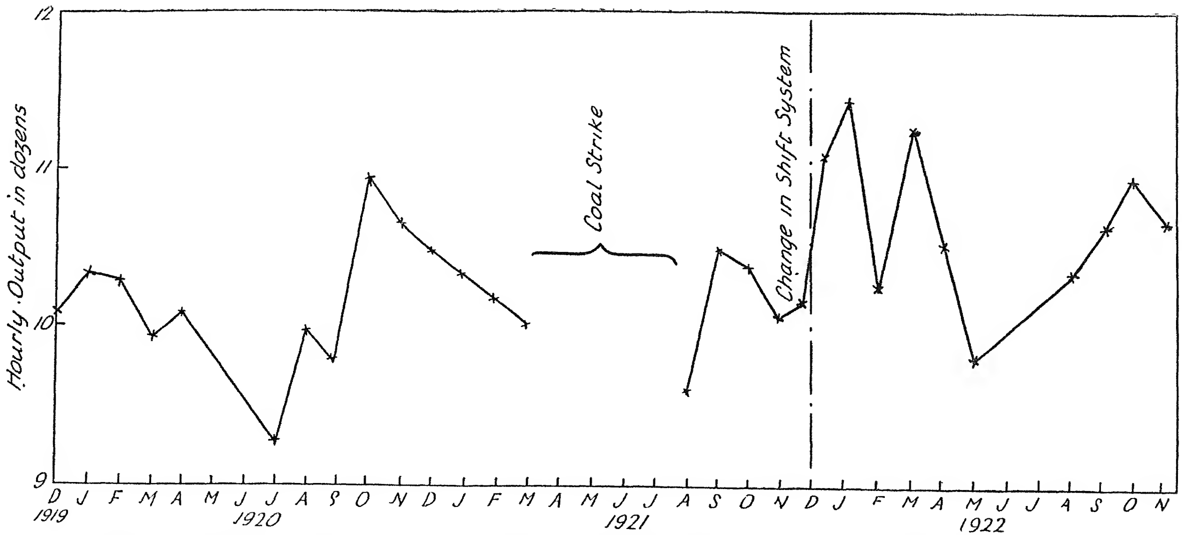

Fig. 1. Monthly variations in hourly output, December, 1919–November, 1922. Machines. Pints.

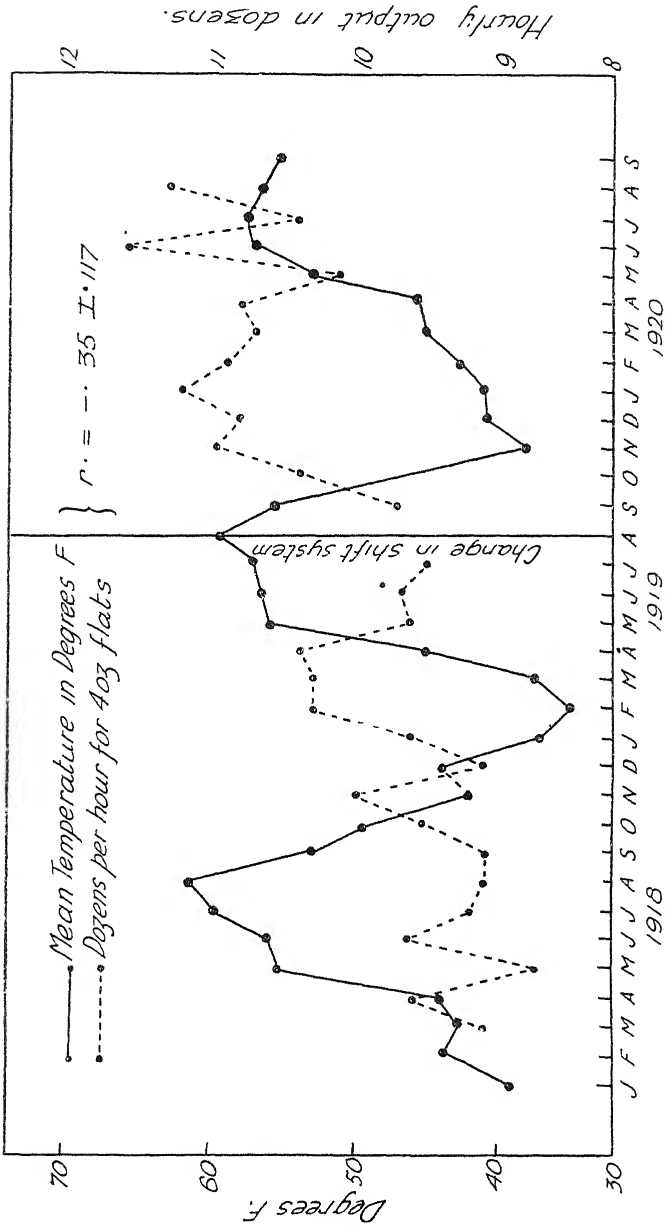

Fig. 2. Seasonal variations in output.

There can be no doubt that part of this increased output is due to a spurt on the part of the workers. This is shown in Fig. 1, where a spurt immediately following the change in shifts is easily discernible. It is also interesting to note that the percentage of spoilt work was particularly high at this period. This spurt seems more marked in the case of the semi-automatic workers (Fig. 1), than in the case of the hand-workers (Fig. 2).

On the other hand, the level of output for the semi-automatic worker after the spurt following the change tends to revert to its original level, whereas the level of output for the hand-workers, although it drops from its initial spurt, tends to assume a higher level than that previously maintained. Possibly the increase in output with handworkers, being more dependent upon the actual lessening of the fatigue of the worker, is less affected by the transitory effects of the spurt. Handwork depends more upon human effort than does semi-automatic work, and therefore reflects more clearly the conditions affecting fatigue. It may be presumed that both hand and semi-automatic workers have a desire to obtain equal results from both the shorter and the longer shifts. In the case of the handworker his lessened fatigue will allow of his putting this desire into operation, whereas in the case of the machine worker, owing to the smaller part played by human effort, the increase in output, apart from the initial spurt, is less. When the increased output is maintained over a long period in a process like glass-blowing, we may assume that it is connected with some fundamental law affecting bodily rhythm. When, however, it tends to pass away after a short period, we may assume that it is due mainly to voluntary effort, and by the nature of things, spurts due to volition must ultimately drop to the level of the normal bodily activity.

Seasonal Variation.

There is a general opinion in the glass industry that output is unfavourably affected by hot weather. Fig. 2 gives the mean temperature for each month for the years 1918–1920 together with the output records of a special article manufactured by the factory in question almost continuously throughout the period. It will be noted that there is a tendency for output to fall when the temperature rises and *vice versa*.* Similar records were obtained from other factories, but although the tendency was in all cases the same, the lines of output were never so continuous as that shown in Fig. 2, and so in order not to complicate the figure unnecessarily they have not been included.

* The co-efficient of correlation between temperature and output is — ·35 ± ·117.

The influence of temperature upon output can also be seen in Fig. 3, which shows the effect of the breakdown of the apparatus for blowing cold air into the mouth of the gathering hole which occurred during the progress of an investigation at one factory.

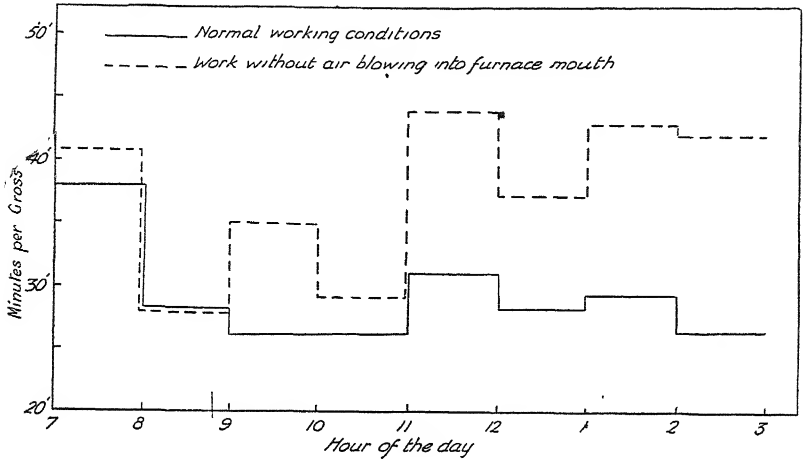

Fig 3. Average hourly time per gross of 9-oz bottles.

The longer time taken to manufacture each gross of bottles when the worker was exposed to the direct heat of the tank is shown by the difference between the two lines. Further, the lines tend to diverge more as the day continues, from which we may conclude that adverse temperature conditions have a cumulative effect in producing fatigue.

The most satisfactory way of further investigating the connection between fatigue and temperature with a view to determining the most efficient method of ventilation for glass works is by means of the kata-thermometer. Most glass factories are provided with systems of artificial ventilation, but in some cases the workers have an objection to using them. In a record such as is given in Fig. 2, there are no means of ascertaining whether the apparatus for artificial ventilation was or was not employed at any particular time. In an intensive investigation with the kata-thermometer this would be known, and an even closer connection might possibly be discovered between fatigue and the cooling power of the air in which the glass blowers work.

*A similar relation between temperature and output has been shown to exist both in the tinplate and in the iron and steel industries.

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* VERNON, H M. (1919): The Influence of Hours of Work and of Ventilation on Output in Tinplate Manufacture (*Ind. Fat. Res. Bd. Report No.* 1).

VERNON, H. M (1920): Fatigue and Efficiency in the Iron and Steel Industry (*Ibid Report No.* 5).

Comparative Efficiency of Shifts.

Fig. 4 shows the relative efficiency of the three shifts throughout the year at one factory. Figs. 5, 6 and 7 show the relative efficiency of the three shifts at three factories throughout the week for the whole period of investigation.

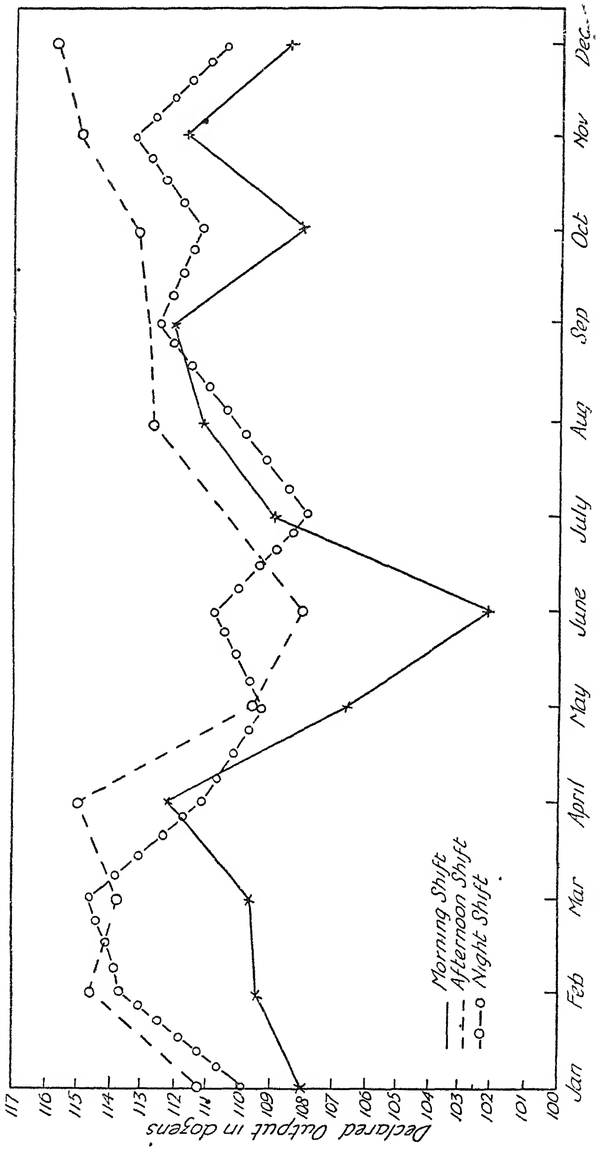

Fig. 4. Comparison between three shifts in 1920 (4-oz flat Ellman's)

These four figures all agree in showing that the morning shift (which lasted from 7 a.m. to 3 p.m. in one case and from 6 a.m. to 2 p.m. in the others) is the least efficient. The possible cause of this relative inefficiency may be that the workers go to

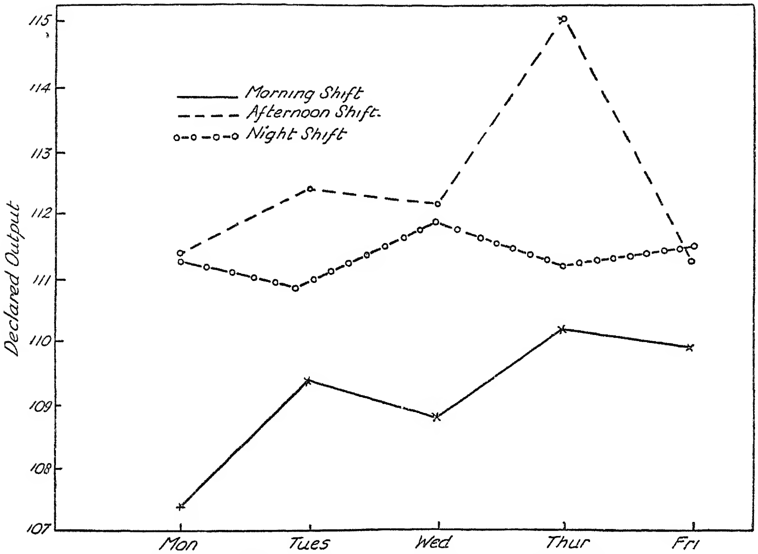

Fig 5 Daily variations in three shifts in 1920.

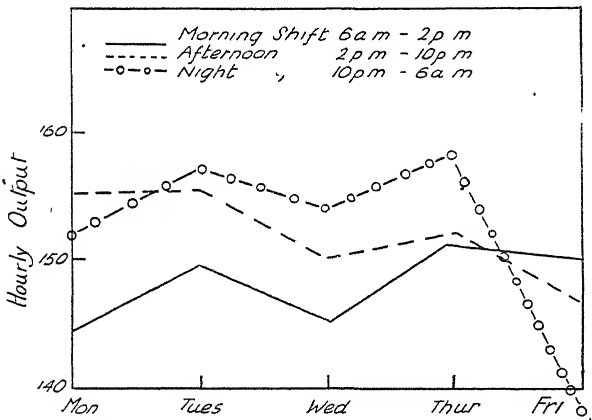

Fig. 6. Daily variations in hourly output according to shifts, August, 1919–March, 1922.

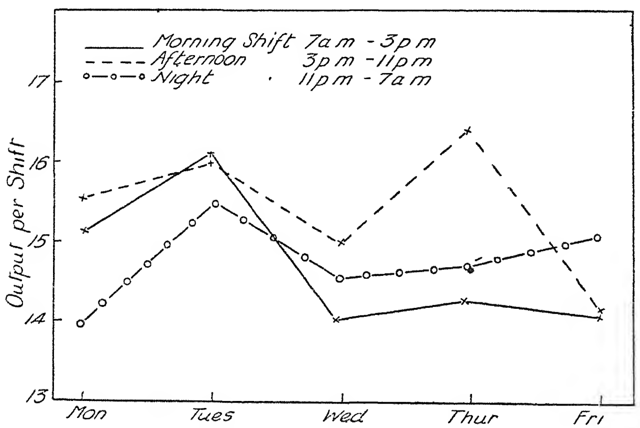

Fig. 7. Average daily output per shift—9-oz. bottle—

the factory without a proper breakfast. Considerable disorganisation would be caused in the household if breakfast was properly prepared and eaten in sufficient time for the worker to be in the factory by 6 or 7 a m., and perhaps on this account the meal tends to be scanty and hurriedly eaten. Another reason may be that the end of this shift when, as is shown in Fig. 3, the workers are more liable to feel the adverse effects of high temperature owing to increasing fatigue, falls within the hottest period of the day. There is a marked fall off in the output of the morning shift shown in Fig. 4 during the summer months, which also goes to show that temperature affects the output of this shift more than the others.

The night shift is, on the whole, less efficient than the afternoon shift, although there are exceptions to this. The difference is, however, not very great and should be compared with the difference between day and night work shown in Fig. 8, which represents the daily output of a factory working the alternative shift system of six hours on and six hours off during the 96 hours of the working week, which lasted only from Monday to Thursday.

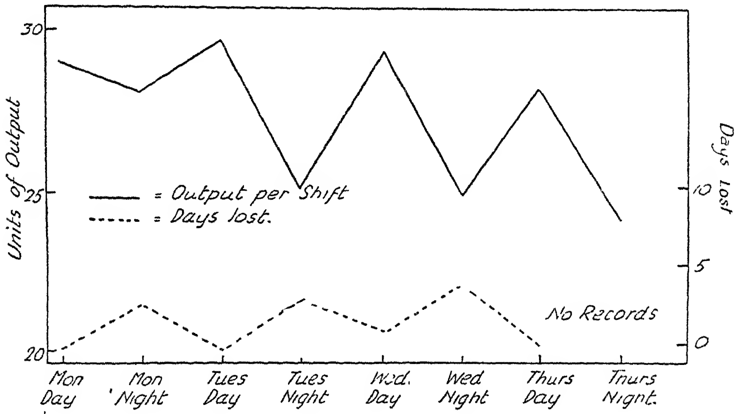

Fig 8. Average daily output of tube drawers on a year's working (1921).

It will be seen that the night shift is always less efficient than the day shift, that its efficiency declines more towards the end of the week, and that there is always more lost time on it. It must obviously be very fatiguing to work twelve hours out of the twenty-four, even if it is divided into two six-hour shifts, and this fatigue seems to show itself in accentuating the difference between day and night work to the great disadvantage of the latter.

This difference in efficiency is also shown in Fig. 9. On only one occasion during the summer is the night shift better than the day. Throughout the year the day shift is 6·1 per cent. better than the night shift.

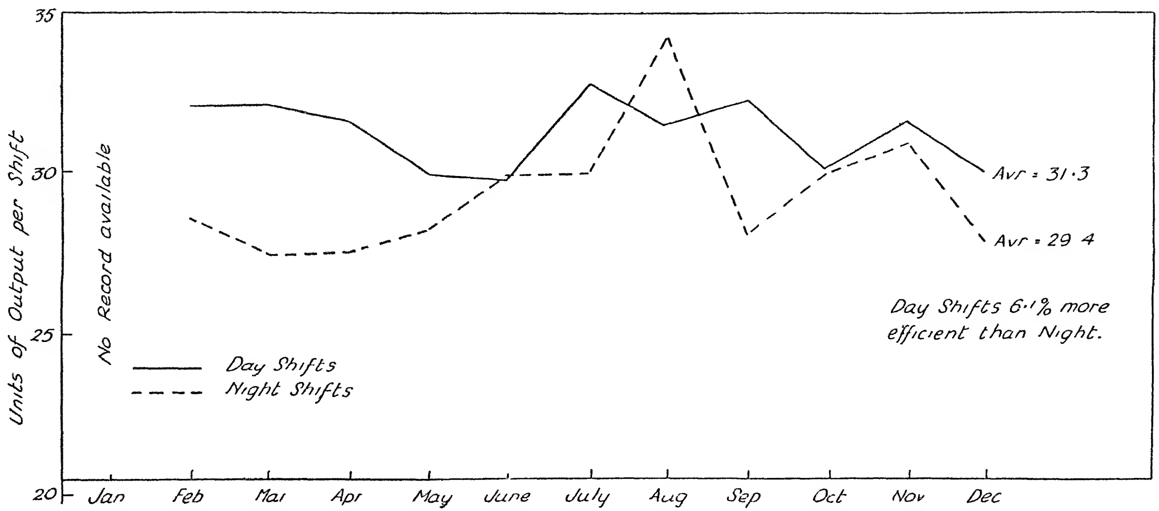

Fig. 9. Tube drawers, average monthly output per day and night six-hour shift, 7 a m –1 0 p.m followed by 7 p.m.–1.0 a.m. (twelve-hour day on four days per week), 1920

Daily Variation in Output.

Daily variations in output were obtained from the firms visited, but they revealed no very striking features, in the case of either the two or three shift system. Fig. 10 shows the percentage variation for the ten-hour shift and the eight-hour shift, and the alternative six-hour shift for four working days of the week.

The method adopted is to find the mean of the daily output and express any variation from this mean as a percentage. By this method curves of output become directly comparable with each other, and differences which they manifest are possible indications of workers' fatigue. It will be seen from Fig. 10 that the curves representing both the ten- and eight-hour shifts (the average of output of the two most reliable sets of records) show comparatively small deviation from their means, the eight-hour shift showing least. The curve representing the alternative six-hour shift method shows considerable variations in Monday's and Thursday's level. If this method of measuring fatigue is valid, we may infer that the alternative method of working is far more fatiguing than either of the other two.*

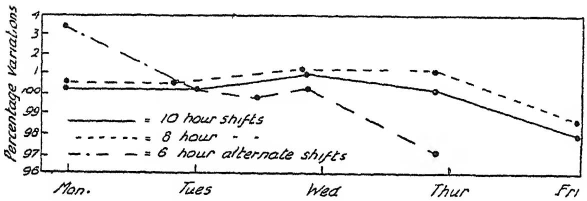

Fig. 10. Percentage efficiency of different shift systems.

Hourly Variation in Output.

Various records of hourly variation were taken, but they have not been incorporated in the report as it was impossible to use these for the purpose of the comparative efficiency of the shifts and as they showed no features of special interest. Their usual features were a "warming-up" period at the beginning of the shift, and a tendency to fall away towards the end, and in most cases there was a short end spurt.

Fig. 11 is given in order to show the effect of rest pauses during the working day. It was obtained by timing the output of a steady worker ten times every quarter of an hour during the afternoon shift for three consecutive days.

It will be noticed that the tea pause of half an hour checks the rise of the curve representing the time required to manufacture the bottle in question, and for some time after that a stable condition of work is maintained. The ten-minute break towards the end of the shift has the effect of considerably reducing the time required to manufacture the article.

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*Farmer, E. (1923): Interpretation and Plotting of Output Curves. *Brit. Jr. Psych.* **13**,3.

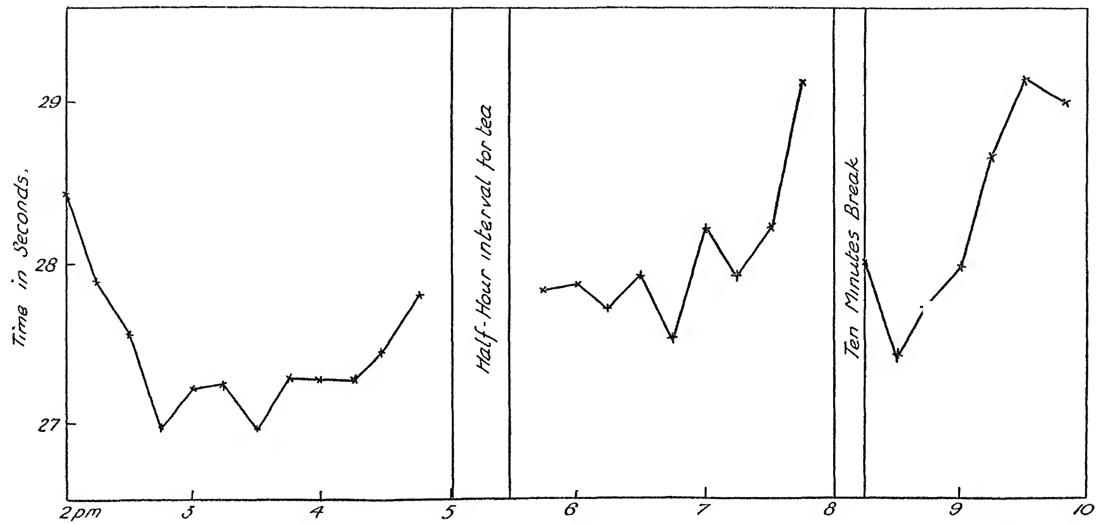

Fig. 11. Time taken by a blower to blow one bottle at different times during the afternoon shift (2–10 p m).

The American System.

Records were obtained from one firm during the investigation concerning the effect of the change of working hours on the American system. In this system the skilled men are employed purely on skilled operations, all other work connected with the manufacture of the bottle being done by unskilled workers. This method of working produces a much higher output than the usual method. The effect of the change of working hours on this system is given in Tables V and VA.

It will be seen that there is a considerable increase in output, which is also accompanied by a slight increase in the amount of spoilt work This increase is partly due to the initial spurt following the change, as shown in Fig. 12, but it is also to be noted that when stability is obtained after the spurt the curve of output is on a higher level than it was before the change. Part of the increase in spoilt work is undoubtedly due to the spurt, since during that period the amount of spoilt work is higher than either before or after.

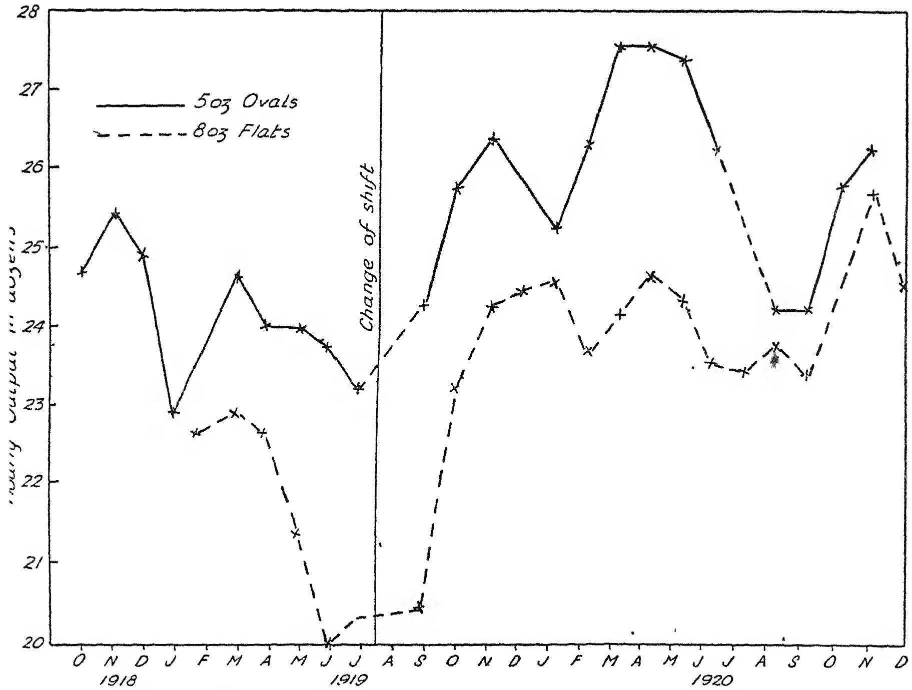

Fig. 12. Monthly variations in declared output, "American system."

No records for heavier bottles were obtainable, but the percentage increase in output on these small bottles is about on the same level as that obtained in other works on bigger bottles, and if the inference drawn from previous data that the increased output due to the shortening of hours is more marked in heavier than in lighter work is correct, we may infer that the increase for heavier bottles under the American system would be proportionately larger.

SUMMARY.

1. Within the limits of the data obtained during this inquiry it is clear that the relative hourly efficiency in bottle blowing has been increased by shortening the hours of work, though this increase is in no case so great as to bring the output of the eight-hour shift to the level of the ten-hour shift. It must, however be borne in mind that the plant in factories employing the three shift system is being productively used for 24 hours per day, whereas in factories employing the two shift system it is only being productively used for 20 hours a day. From this it follows that the total output per day is greater with the three shift system than with the two shift system.

2. Night work in the three shift system does not appear to put a markedly greater strain on the men than day work. The night shift is always more efficient than the morning shift and not much less efficient than the afternoon shift. When 12 hours' work out of 24 hours is done in alternate six-hour shifts, night work is consistently less efficient than day work.

3. There is evidence of seasonal variation in output, and a more detailed inquiry into the effect of temperature on output is desirable. In order to do this satisfactorily, it would be necessary to take kata-thermometer readings in various factories at various times of the day and at various seasons of the year. The practical outcome of such an inquiry would be to throw some light on the most efficient method of artificial ventilation.

4. An interesting experiment with a view to relieving fatigue and increasing efficiency could be carried out by alternating the work of each member of a *chair* or gang. At present, the same work is done throughout the whole shift by each member of the group. The task of gathering the molten glass from the pot is undoubtedly the most exhausting process, and yet the rate of production is almost entirely dependent on the worker who performs this operation. It is probable that fatigue could be considerably relieved if the men took turns at this. In some of the subsidiary processes the worker sits down so that an alternation in the method of working would involve a change from a standing to a sitting position, which would probably have beneficial results.

5. Great care has been exercised in this inquiry only to use reliable data. Much of the material obtained was not made use of, because it was affected by interfering factors, the importance of which could not be determined. For this reason the data are not so voluminous as might be desired, but are undoubtedly of a kind from which conclusions can be safely drawn.

APPENDIX I.

The Effect of Practice.

Figure 13 is given in order to show the part played by practice in the manufacture of glass bottles. The data were obtained from a factory using a semi-automatic process of bottle manufacture, and give the average output per shift each week until relative stability is attained. The earlier weeks are not included, as during this period the workers in question were suffering from difficulty with their moulds. The bottle being made was one of which the firm manufactured a considerable quantity, but there had been a stoppage in its manufacture for some time previous to this period A and C were both experienced gatherers, and had previously been employed on the manufacture of this particular bottle.

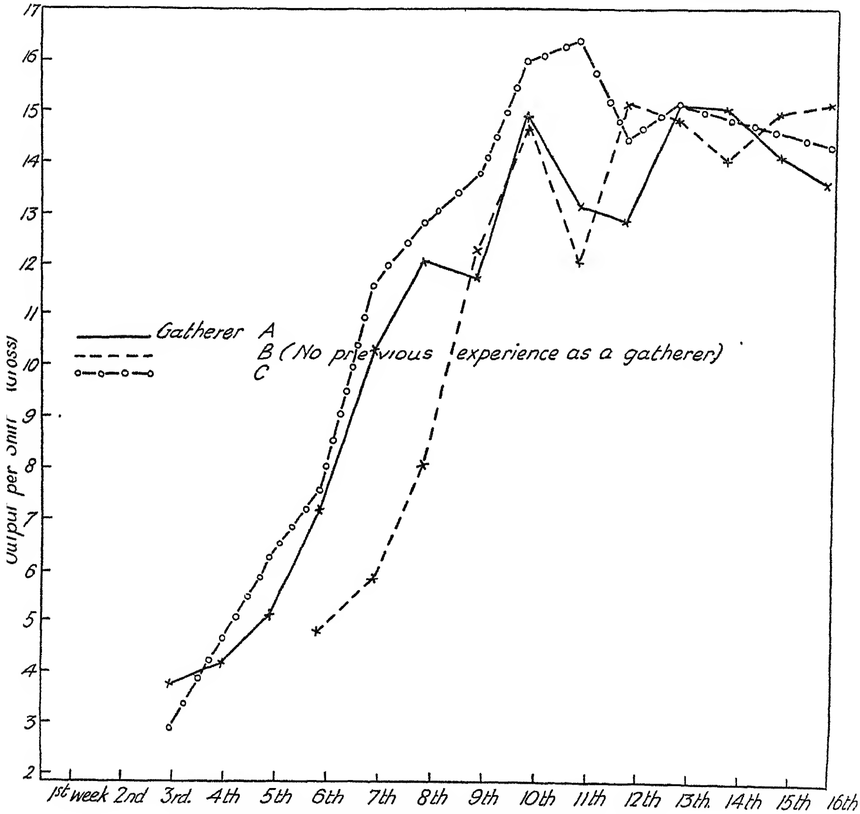

Fig. 13. Effect of practice on output, 9-oz. bottle.

B had never previously been employed as a gatherer. The results show that it is not until the tenth week that equilibrium is reached and it is also interesting to note that B, although he had had no previous experience in gathering, is very little behind the others in efficiency and when stability is finally reached is practically equal to them. This figure is given in order to show how much more economic it is to manufacture long runs of the same article, and with what comparative ease a beginner can acquire sufficient skill to become an efficient gatherer. The skill employed in gathering appears to lie more in judging the amount of glass necessary for the particular article than in its actual manipulation. All three gatherers take approximately ten weeks to become accustomed to this, and previous experience seems to play very little part in it. This figure should be compared with Fig. 14.

APPENDIX II.

The Effect of Stoppages.

Fig. 14 shows the effect on output of two stoppages in a glass works during 1921. The first was due to the coal strike and the second to the influenza epidemic. The drop in output which precedes the stoppage owing to the coal strike is probably due to using insufficient coal in an attempt to avert complete stoppage The average efficiency of both shifts is lower after the long stoppage due to the coal strike and the efficiency

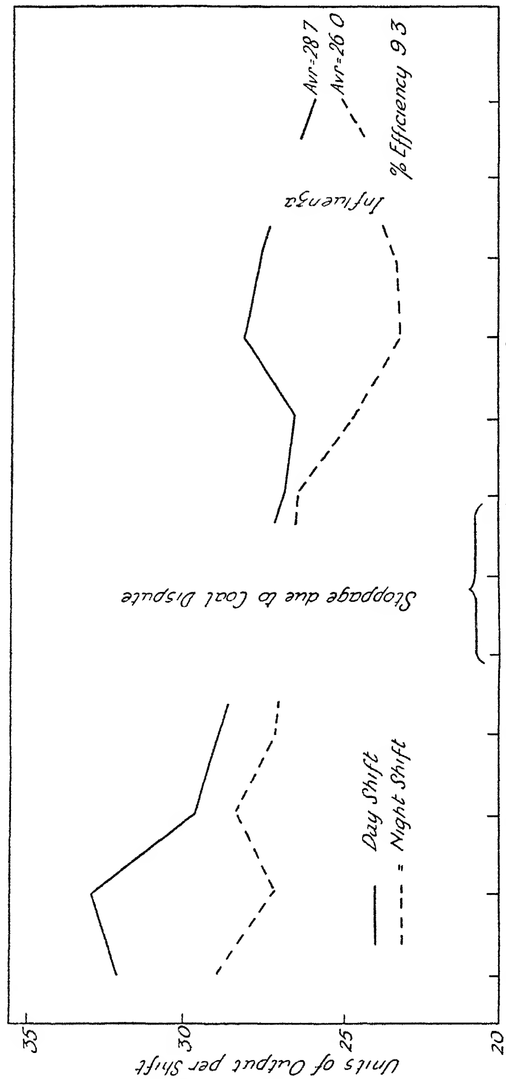

Fig 14 Average monthly output per day and night six-hour shift 7.0 a m –1 0 p m. followed by 7.0 p.m.–1.0 a.m. (twelve-hour day on four days a week).

of the day shift is lower after the stoppage due to influenza, though that of the night shift is higher. The loss of efficiency through stopping is probably caused by the men losing, to some extent, their motor dexterity through want of practice.

The data contained in Fig. 13 are sufficient to show that this is the case, and the evidence obtained from this other factory corroborates it. It should, however, be borne in mind that part of the drop after the coal strike may have been due to the hot weather.

TABLES.

TABLE I.—*Showing the effect of shortened hours on hourly output (Hand-made processes).*

Factory.	Bottle.	Ten-Hour Shift.				Eight-Hour Shift.				Percent. Diff. in hourly output		Periods Investigated.	
		Output per Shift	Number of Records	Standard Deviation	Hourly Output	Output per Shift.	Number of Records.	Standard Deviation.	Hourly Output.	Increase	Decrease	Ten-Hour Shift	Eight-Hour Shift.
1.	1 oz. Vial ..	1907	10	*64·7*	200·7	1428	29	*61·8*	196·9	—	1·9	Jan –June, '17	Jan -Mar and Oct.-Dec., '21
	6 oz Flats ..	1466	90	*99·6*	153·6	1109	74	*75·8*	152·9	—	0·5	Jan.'17–Dec.'18	July '19–Dec '21
	8 oz ,, ..	1389	85	*99·6*	145·4	1096	115	*74·1*	151·2	3·9	—	,, ,,	,, ,,
	20 oz. Corbyns	1081	7	*82·4*	113·8	902	10	*57·7*	124·4	9·3	—	1917 and 1918	1920 and 1921
	24 oz ,,	1009	14	*58·6*	106·2	878	33	*53·4*	121·1	14·0	—	,, ,,	,, ,,
	32 oz ,,	844	11	*42·1*	88·8	765	6	*54·8*	106·2	19·6	—	,, ,,	,, ,,
	80 oz. ,,	425·6	3	*15 3*	44·8	390·8	13	*32·7*	53·9	20·3	—	1918	,, ,,
	90 oz ,	366·7	7	*17·3*	38·6	342·2	14	*55·6*	47·2	22·3	—	,,	,, ,,
2.	2 oz.	2036·0	41	*19·5*	214·3	1736·1	25	*60·5*	239·4	11·7	—	Mar.'18–Feb '19	Jan –Dec. '20
	3 oz.	2002·6	40	*59·6*	210·8	1632·1	32	*35·3*	225·1	6·8	—	,, ,,	,, ,,
	4 oz	1956·5	66	*82·4*	205·9	1567·8	144	*34·2*	216·2	5·0	—	, ,,	,, ,,
	6 oz.	1835·2	145	*91·9*	193·2	1486·3	243	*39·2*	205·1	6·2	—	,, ,,	,, ,,
	8 oz	1818·8	382	*85·2*	191 4	1428·6	680	*83·6*	197·0	2·9	—	,, ,,	,, ,,
	10. oz. ..	1662·8	13	*54·3*	175 0	1354·0	38	*68·1*	186·7	6·6	—	,, ,	,, ,,
	12 oz ..	1564·3	30	*34·4*	164·6	1276·2	56	*51·9*	176·0	6·9	—	,, ,,	,, ,,
	16 oz ..	1326·4	8	*7·1*	139·6	1143·9	19	*39·4*	155·8	11·6	—	,, ,,	,, ,,
3.*	4 oz Flats ..	133·6	203	*8·7*	14 0	111·0	414	*7·3*	15·9	8·9	—	Mar.'18–Feb.'19	Apr.'20–Mar '21
	10 oz. Rounds	112·6	52	*6·4*	11·8	95·2	64	*5·9*	13·1	10·9	—	,, ,,	,, ,,
	Pints	100·6	76	*14·2*	10·6	89·9	112	*6·5*	12·2	15·7	—	Sep.'18–June'19	Sept '19–June'20
	10 oz. Codds ..	89·2	108	*8·7*	9·4	77·2	34	*4·3*	10·6	12·9	—	Mar.'18–Feb.'19	Apr.'20–Mar.'21
4.	6 oz. Medical ..	1427·8	18	*93·8*	150·6	1219·5	42	*77·9*	169·7	12·6	—	1917	1920
	8 oz. ,, ..	1330·5	43	*93·4*	140·4	1143·0	86	*65·6*	159·5	13·6	—	,,	,,

*Output in this factory is given in dozens.

TABLE II.—*Showing the effect of shortened hours on percentage of work spoilt (Hand-made-processes).*

Factory.	Bottle	Ten-Hour Shift						Eight-Hour Shift						Percentage Difference.	
		Declared	Standard Deviation	Drawn	Standard Deviation	Number of Records	Percentage Spoilt	Declared	Standard Deviation.	Drawn	Standard Deviation	Number of Records.	Percentage Spoilt	Increase	Decrease
2	2 oz.	2036·0	*19·5*	1985·0	*49 1*	41	2·5	1736·1	*60·5*	1703 0	*91·4*	25	1·9	—	0·6
	3 oz	2002·6	*59·6*	1928·6	*83 2*	40	3·7	1632·1	*35·3*	1582·3	*120·4*	32	3·1	—	0·6
	4 oz.	1956·5	*82·4*	1885·1	*89·7*	66	3·6	1567·8	*34·2*	1519·4	*107·0*	144	3·1	—	0·5
	6 oz.	1835·2	*91·9*	1784·1	*33·2*	145	2·8	1486·3	*39·2*	1438·8	*122·8*	243	3·2	0 4	—
	8 oz.	1818·8	*85·2*	1762·1	*98·1*	382	3·1	1428·6	*83·6*	1380·6	*87·3*	680	3·4	0 3	—
	10 oz. ..	1662·8	*54·3*	1632·5	*66 1*	13	1·8	1354·0	*68·1*	1305·0	*70·1*	38	3·6	1·8	—
	12 oz ..	1564·3	*34·4*	1529·3	*51 1*	30	2·2	1276·2	*51·9*	1220·9	*60·4*	56	4·3	2·1	—
	16 oz ..	1326·4	*7·1*	1312·5	*10 0*	8	1·0	1143·9	*39 4*	1098·9	*41·2*	19	3·9	2·9	—
3.	4 oz. Flats ..	132·5	*12·5*	125·9	*12 5*	209	5·2	109·8	*6·2*	105·1	*6·3*	321	4·5	—	0·7
4	6 oz. Medicals	1427·8	*93·8*	1349·1	*102·5*	18	5·5	1219·5	*77·9*	1147·6	*74·0*	56	5·9	0·4	—
	8 oz. ,,	1330·5	*93·4*	1227·9	*109·0*	43	7·7	1143·0	*65·6*	1101·4	*95·7*	86	8·9	1·2	—

TABLE III.—*Showing the effect of shortened hours on time lost through absence.* (*Factory I.*)

Absences.	Ten-Hour Shift.			Eight-Hour Shift.			Decrease.
	Percentage Time Lost Monthly.	Standard Deviation.	Number of Records.	Percentage Time Lost Monthly.	Standard Deviation.	Number of Records.	
Under four consecutive weeks	3·15	*1·76*	24	3·05	*1·43*	22	0·10
Two days and under ..	1·31	*0·47*	24	1·15	*0·59*	22	0·16

Factory	Bottle	Ten-Hour Shift				Eight Hour Shift.				Percent. Diff. in hourly output.		Periods Investigated.	
		Output per Shift	Number of Records.	Standard Deviation	Hourly Output	Output per Shift	Number of Records	Standard Deviation.	Hourly Output.	Increase	Decrease	Ten-Hour Shift	Eight-Hour Shift.
3.	2 lb. Jam ..	148·9	332	*15·0*	15·65	119·4	363	*9·3*	16·48	5·3	—	Oct '18–July '19	Aug '19–Mar. '20
5	2 lb ,, ..	100·1	93	*13 7*	10·54	103·2	381	*7·3*	14·26	35·3	—	Sept. '16–Apr. '17 Feb. and July '19	Aug '19–Aug. '20
6	Pints	96·2	481	*7·0*	10·13	77 6	231	*4·6*	10·70	5·6	—	Dec '19–Dec. '21	Dec. '21-Nov. '22
	Quarts ..	80·0	1014	*8·6*	8·42	67·3	376	*5·7*	9·28	10·2	—	Jan '20–Nov '21	Dec. '21-Nov. '22

TABLE IVA.—*Showing the effect of shortened hours on percentage of work spoilt (Semi-Automatic Machines).*

Factory	Bottle.	Ten-Hour Shift						Eight-Hour Shift.						Percent. Diff. in hourly output.	
		Declared	Standard Deviation	Drawn	Standard Deviation.	Number of Records.	Percentage Spoilt.	Declared.	Standard Deviation	Drawn.	Standard Deviation	Number of Records.	Percentage Spoilt	Increase	Decrease
3.	2 lb Jam ..	148·9	*15·0*	135·8	*16·9*	332	10·6	119·4	*9·3*	109·4	*12·7*	363	8 8	—	1·8
5.	2 lb. ,, ..	100·1	*13·7*	95·3	*16·1*	92	7·4	103·2	*7·3*	96·9	*8·2*	381	7·3	—	0·1
6.	Pints	96·2	*7·0*	89·4	*6·8*	481	7 8	77 6	*4·6*	68·9	*5·5*	231	15·8	8·0	—
	Quarts ..	80·0	*8·6*	72·21	*9·3*	1014	13·5	67·3	*5·7*	59·8	*6·2*	376	16·1	2·6	—

TABLE V.—*Showing the effect of shortened hours on the hourly output for American System.*

Factory	Bottle.	Ten-Hour Shift.				Eight-Hour Shift				Percent. Diff. in hourly output		Periods Investigated.	
		Output per Shift.	Number of Records.	Standard Deviation	Hourly Output	Output per Shift	Number of Records	Standard Deviation	Hourly Output	Increase	Decrease	Ten Hour Shift	Eight Hour Shift
3.	5 oz	230·3	239	*16·6*	24·27	188·6	568	*18·7*	26·34	8·5	—	Oct.'18–July '19	Sept '19–Nov.'20
	8 oz.	206·5	162	*21·3*	22·03	174·3	458	*15·3*	24·70	12·1	—	Feb '19–July'19	Sept '19–Dec '20

TABLE VA.—*Showing the effect of shortened hours on percentage of work spoilt for American System.* (*Factory* 3).

Bottle	Ten-Hour Shift.						Eight-Hour Shift						Percentage Difference.	
	Declared.	Standard Deviation.	Drawn.	Standard Deviation	Number of Records.	Percentage Spoilt	Declared	Standard Deviation	Drawn	Standard Deviation	Number of Records	Percentage Spoilt	Increase	Decrease
5 oz. ..	230·3	*16·6*	217·2	*17·7*	239	5·7	188·6	*18·7*	175·5	*22·1*	568	7·1	1·4	—
8 oz. ..	206·5	*21·3*	191·9	*21·9*	162	6·5	174·3	*15·3*	157·3	*19·6*	458	10·3	3·8	—

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